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Final Report

DEVELOPMENT OF A PROTOTYPE SYSTEM FOR SNOW ROUTE DESIGN AND MANAGEMENT

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1. EXECUTIVE SUMMARY

Work has recently been completed on the design and development of a prototype system for snow route design and management. The results of this research fall into three separate, but related areas: 1) analysis of analytical procedures available for performing route design and analysis, 2) analysis of data availability and adaptability to support these analytical procedures, and 3) consideration of the appropriate user environment for conducting route design and analysis within the protocols presently recognized by the Indiana Department of Highways (IDOH). Results from this research, which will be described in detail in this report, are summarized as follows:

1. Network optimization methods may be applied to problems of routing service activities for those cases where complete and accurate data exist about the specific configuration of the network including road segment adjacency through intersections and segment distances. However, the result of this type of analysis should not be expected to be an implementable route design strategy because the level of resolution of such models is not sufficient for representing operational capability; the resulting route should be interpreted as a good starting point for interactive route design by an experienced engineer.

2. Improvement in route specifications may be expected though the computational effort required for some network segments may be significant and even prohibitive is some cases. For service areas characterized by rural areas, improvements in existing routes in terms of reduced deadheading may be expected in all service areas. In some cases, reduction in numbers of routes may be expected. However, for heavily urban areas such as the Indianapolis area, an optimization procedure will likely not be effective.

3. The cost effectiveness of the use of these models depends on the level of effort required to collect and input required data. However, satisfactory data already exist for use by these techniques, and knowledge-based techniques for "filtering" these data to accommodate the spatial resolution required for IDOH applications have been developed.

4. In most cases, route design is not an activity that needs to be conducted in real time, or even on a regular basis. Consequently, the availability of extensive (and expensive) computer systems at all locations where activity planning is conducted is not a major requirement of a route design system.
5. The needs of urban areas relative to route design and planning are significantly different from rural areas. Special modeling techniques that are very different from the optimization approach discussed in previous research (cited above) are needed.

The application of systems methodologies to problems of route design and planning, therefore, depend on two considerations. First, can the systems models, when properly applied to the problem domain, generate routing solutions that are by some measure superior to existing routes or those that would be developed without the aid of these models? And second, can the data required to use these models be acquired in a cost effective manner? Clearly, if the cost in time and/or dollars to collect data for the models are excessive, the likelihood of their use is greatly reduced. Both of these issues have been carefully investigated and further development is warranted.

2. STATEMENT OF THE PROBLEM

The quality of services provided by public institutions is often very difficult to quantify. In contrast to the private sector, where engineering management objectives are usually specified in terms of economic efficiency, government agencies strive to provide the "best" level of service possible as measured by public welfare and safety. These performance criteria are generally difficult to quantify for most public service activities. An important factor, however, in the quality of services provided is the planning and management of those services. For an institution such as the Indiana Department of Highways (IDOH), a key factor in effective planning and management is the ability to design efficient route configurations for the delivery of services.

The removal of snow and ice from the intrastate highway system is a good case in point. As with many public-sector management operations, snow and ice control may be viewed as a series of discrete sub-problems: 1) the locating and sizing of facilities for storage of salt and abrasive material as well as maintenance vehicles and equipment; 2) the partitioning of the physical system into sub-areas that are manageable from the standpoint of administration; 3) the definition and assignment of vehicle routes; and 4) the assignment of available personnel to snow and ice control routes. While other decompositions are possible (1-4), this scheme best describes the problem faced by the IDOH.

In developing a strategy for winter season snow and ice removal, the goal of (IDOH) is to provide efficient service within the constraints on available resources; plowing and abrasive spreading equipment, sand and salt supplies, and manpower. While holding down overall cost is a primary consideration, the safety of the public is the major objective (5). Public safety in this context has two distinct but related components: 1) the condition of the road surface (6), and 2) the performance of the snow removal fleet during the operation. An effective snow removal operation is one that provides rapid and orderly snow removal and abrasive application without excessive interference with public transportation activity (5-7).

The routing of vehicles for snow and ice control is the most difficult of public-sector routing problem. Yet the data required for solving this problem are not significantly different than those required for other service planning and management problems. Consequently, the resulting system will be of use to maintenance engineers for a wide range of applications such as scheduling and routing of mowing, painting, weed control, facilities and equipment servicing, inspection, and possibly some pavement maintenance activities.

2.1 Vehicle Routing and Scheduling

The topic of vehicle routing and scheduling covers such activities as retail distribution, school bus routing, mail delivery, street sweeping and snow removal, waste collection, and communications system management. Yet given this diverse spectrum of applications the entire field of study can be partitioned into two major categories: 1) routing vehicles where one is only concerned with developing a set of routes to satisfy demand at several points or streets, and 2) scheduling vehicles where one is concerned with satisfying demand given time windows or precedence relations with regard to the demand points. Some literature chooses to make the major partition of the topic at demand type. That is, does the demand for service originate from points making it a node covering problem or does it exist along the length of the street making it an arc covering problem.

The paper by Bodin and Golden (9) provides an excellent taxonomy for vehicle routing and scheduling. It demonstrates the wide range of problem characteristics that can exist when a real world problem is modeled for solution in the abstract. This paper then goes on to provide a general classification of solution strategies for the general vehicle routing problem and several examples of scheduling problems and how they are solved. Alternately, the paper by Golden (10) contains a rather thorough coverage of the traveling salesman problem and general vehicle routing, but is lacking in its coverage of the Chinese postman problem or arc covering applications. Golden has broken the area of routing into three principle network theories, the traveling salesman problem, the vehicle routing problem, and the Chinese postman problem. He describes very well the topic of the traveling salesman problem from both perspectives, exact solution procedures and heuristics.

2.2 Special Considerations for Snow and Ice Control

Snow and ice control during the winter months in Indiana is a major operation (8). The Department must routinely maintain some 11,414 miles of roadway throughout the state. Because each traffic lane must receive service, this translates into more than 29,000 miles overall. The resources needed for this operation include nearly 1,500 trained personnel and some 1,088 maintenance vehicles. The cost is enormous; over $12-million was budgeted by the State of Indiana to support the operation during the 1985-86 winter season.

The management of the operation is extremely complex due to several factors. In addition to the magnitude of the overall operation, uncertainties as to the duration and severity of the snow emergency pose special problems. State roads are categorized into three classifications based on historical average daily traffic (ADT). Class I roads (major traffic arteries including interstates and their associated ramps and roads with ADT greater than 5000) receive continuous service including plowing and the application of chemicals and abrasives as needed to keep the road surface wet and bare. Class II roads (routes having ADT between 1000 and 5000) receive continuous plowing and sufficient chemicals and abrasives to maintain a bare wet pavement in the center portion of the roadway. Class III roads (ADT less than 1000) receive enough service to keep the routes passable, with chemical treatment only for hills, curves and intersections. However, due to uncertainties associated with snow episodes, these criteria serve only as general guidelines; actual service levels are often determined as the operation progresses.

Following a snow episode, extensive "clean-up" activities must be instituted consisting of additional plowing and spot application of chemicals to remove all remaining snow from driving surfaces. This also includes clearing of shoulder areas and special servicing of drains, overpasses and bridges, drifts, and the maintenance equipment itself. Timing is extremely important in all phases of the operation.

Snow and ice control is administered at the sub-district and site level consistent with pre-established "snow routes" of which there are some 986 at present. Routes proper may not begin at a site location. In cases where a truck must travel to the starting point of a route, no service will be conducted during this time. Such travel is referred to as "deadhead" travel. Deadhead miles account for nearly 9,000 vehicle miles per season. Though travel times will fluctuate with overall conditions, design operation calls for plowing intensities dependent on roadway classification. In general, a route may be completely serviced in 2 -2.5 hrs.

Finally, the operation is complicated by the presence of public traffic. Plowing and spreading is most effective within a range of speed for the maintenance vehicle. When vehicle movement is restricted, performance decreases and road conditions will further deteriorate causing additional problems and potentially dangerous conditions.

In designing an overall management strategy for snow and ice control, a number of difficult questions may be posed: What is the best set of routes for maintenance vehicles so as to minimize overall deadhead miles (minimize excess cost)? What characteristics of individual routes are most important in terms of overall safety of operation? How best should vehicles be re-stocked with sand and chemicals during the operation? What contingencies should be provided to compensate for the uncertainties of storm intensity? What is the best allocation of vehicles to sites and routes to vehicles? Are the current administrative boundaries optimal or should the configuration of sub-districts be modified? Where should new facilities be constructed to best enhance overall system performance? These questions and more should be considered in the design of an effective strategy for conducting winter road maintenance.

3. MODEL STRUCTURE AND EXPECTED RESULTS

3.1 Prototype Model Structure and Function

The focus of this section is the description of the evolution of an arc covering algorithm for the design of snow removal routes. One of the first considerations in the design of any algorithm is the data format and structure. For the snow control problem, the primary source of data is the network of state and county roads that may be modeled as a large link-node diagram. Each road is represented as a directed link with attributes such as length, class or priority, and the start and end nodes. The nodes represent the intersection of two or more roads, a depot, or a point where a vehicle may turn around. The next section of this report provides a more detailed description of the data considerations with regard to the readily available digital roadway data from the USGS. Throughout this research, all algorithm and model development has been done with the benefits and current limitations of the aforementioned source of digital data in mind. The design of a system for establishing a database of this type using existing digital maps is the focus of the following Chapter. With a viable source and structure for the data, we may now consider an exact algorithmic approach to the problem of designing snow routes.

In the world of network algorithms the problem of snow removal is an arc covering application in that we are concerned with covering every, or a subset of every, link or road in the network. The basic mathematical programming formulation for this application is known as the Chinese Postman Problem (CPP). The objective of the CPP is to find the least cost path through the network which covers every arc at least once and starts and ends at the same node. For the snow removal problem least cost is minimum distance and arcs that are traversed more than once are tallied up as deadhead miles; for our purposes the CPP models one tuck with infinite capacity starting from and returning to a common depot with the of objective covering every road in the network while minimizing total deadhead miles. Though this is not a realistic representation of the actual multiple truck and depot problem, it does provide a lower bound on how well we can hope to do and a good starting point for more complex models. Our CPP mathematical program is a minimum cost flow based formulation and is shown below:

$$\text{Minimize} \quad \sum_{i=1}^{n}\sum_{j=1}^{n} d_{ij}\, x_{ij} \tag{1}$$

$$\text{Subject to:} \sum_{k=1}^{n} x_{ki} - \sum_{k=1}^{n} x_{ik} = 0 \qquad \text{for all } i \tag{2}$$

$$x_{ij} \geq 1 \text{ \& integer} \qquad \text{for all } (i,j) \tag{3}$$

In this formulation x_{ij} represents how many times the arc (i,j) is covered in the optimal solution. The objective (Equation 1) is to minimize the total distance traveled, which is the summation of how many times an arc is covered, x_{ij}, times the length of the arc, d_{ij}. The first constraint set (Equation 2) enforces flow continuity for all n nodes in the networks; every time a truck enters a node it must also leave that node. The final constraint set (Equation 3) states that every arc must be covered at least once and that the answers must be integer. It makes no sense to say that the truck must cover any given arc a fractional number of times. Finally, though this is an integer or discrete formulation, it will result in integer solutions when solved as a continuous linear program because of the unimodular constraint matrix.

The first step toward model realism is to realize that IDOH is only responsible for a subset of all the roads in the state. That is, IDOH only has to service state roads, highways, and interstates, but their trucks may very well need to traverse a county road to provide service to a state road. Therefore city streets and county roads should be included in the data, but with a flag designating them as merely non-required arcs that may be used to provide more efficient service or reduce deadheading miles. With the data so marked a variant of the CPP known as the Rural Postman Problem, R-CPP, can be used to solve the problem. The formulation is identical to the CPP except for the addition of one constraint and is shown below:

$$\text{Minimize} \quad \sum_{i=1}^{n}\sum_{j=1}^{n} d_{ij}\, x_{ij} \tag{1}$$

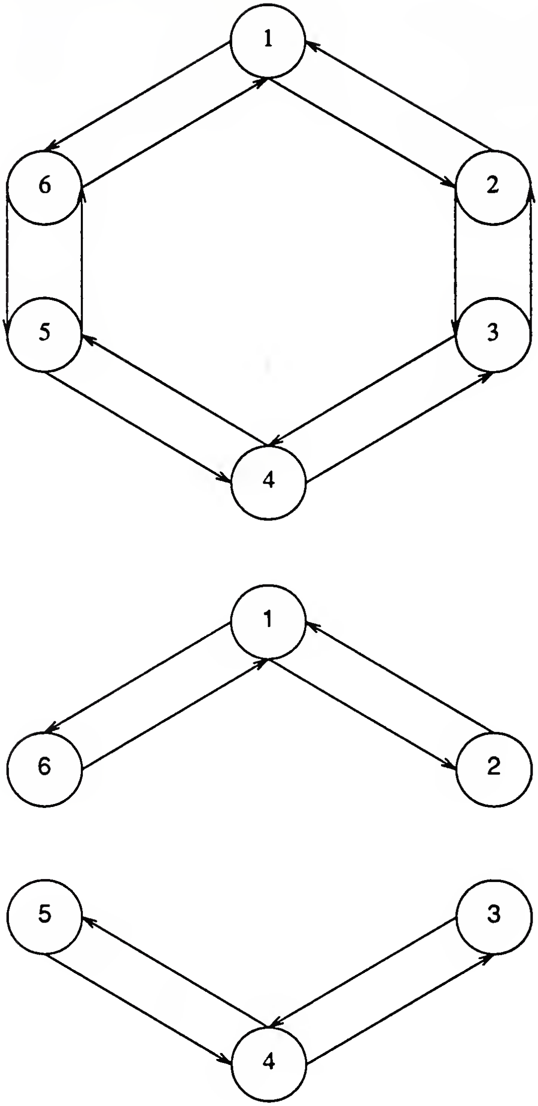
$$\text{Subject to:} \quad \sum_{k=1}^{n} x_{ki} - \sum_{k=1}^{n} x_{ik} = 0 \qquad \text{for all } i \tag{2}$$

$$x_{ij} \geq 1 \ \&\ \text{integer} \qquad \text{for all } (i,j) \in R \tag{3}$$

$$x_{ij} \geq 0 \ \&\ \text{integer} \qquad \text{for all } (i,j) \in (A-R) \tag{4}$$

This formulation employs the notion of the set R which denotes the set of all arcs that IDOH is required to service and the set A which is the set of all of the arcs in the network. Therefore the additional constraint set (Equation 4) states that all arcs that are not required to be serviced by IDOH do not have to be covered, but may be traversed. This discrete model will solve integer when run as a linear program, but a major problem can develop. Consider the simple six node example of the network below (Figure 1A) and its corresponding solution when a R-CPP is run (Figure 1B). Note: arc lengths are irrelevant and arcs (3,4), (4,3), (2,6), and (6,2) are not required.

This example demonstrates the very common and frustrating occurrence of subtour generation. The solution in Figure 1B is optimal, but represents an impossible route for a truck to traverse because of the existence of two subtours: (1->2->1->6->1) and (3->4->5->4->3). There is no way to trace a path from node one which covers all of the



A

B

FIGURE 1 - Arc-Node Configuration for Optimization Model

required arcs and returns to node one.

Subtour generation is the major stumbling block in the formulation of any type of exact routing algorithm. There is a large body of literature that addresses this problem from many different angles, but for our current purpose, an exact solution for the R-CPP, it is sufficient to discuss only one. The subtours could be eliminated if there existed constraints in the R-CPP formulation that would not allow them to be formed in the first place. The problem with these constraints is that there are an exponential number of possible subtours that can be formed, based on the number of nodes, therefore there are an exponential number of possible constraints that could be added to the model to stop their formation. Two problems exist with these additional constraints: one, for problems of any realistic size, say 100 plus nodes, the number of subtour breaking constraints grows to an outlandish size and two, these constraints force the model off of integer linear programming solutions. With the loss of integer linear programming solutions we are forced to employ an integer programming code such as branch and bound which could enumerate for eternity with a problem of 100 plus integer variables and an exponential number of constraints and never find an optimal solution. But before giving up entirely on the CPP based exact approach, let us evolve the model one step further by imposing the fact that multiple trucks will be used to service the network.

The previous model, R-CPP, used the idealized one truck of infinite capacity. Indiana's current snow control operations utilize multiple trucks emanating and returning to a common depot of which there are several grouped into subdistricts that in turn are part of larger districts. If we restrict our resolution to one depot in any given subdistrict, the R-CPP may be extended to accommodate multiple vehicles and result in a formulation we will call the M-Rural Postman Problem, MR-CPP. This mathematical program is a bit more complex and is shown below:

Minimize $$\sum_{i=1}^{n}\sum_{j=1}^{n}\sum_{k=1}^{m} d_{ij}\, x_{ij}^{m} \tag{5}$$

Subject to: $$\sum_{k=1}^{n} x_{ki}^{m} - \sum_{k=1}^{n} x_{ik}^{m} = 0 \qquad \text{for all } i, m \tag{6}$$

$$\sum_{i=1}^{n}\sum_{j=1}^{n} d_{ij}\, x_{ij}^{m} \le \text{MAXMILES} \qquad \text{for all } m \tag{7}$$

$$\sum_{k=1}^{m} x_{ij}^{m} \ge 1 \text{ \& integer} \qquad \text{for all } (i,j) \in R \tag{8}$$

$$\sum_{k=1}^{m} x_{ij}^{m} \ge 0 \text{ \& integer} \qquad \text{for all } (i,j) \in (A-R) \tag{9}$$

$$x_{depot}^{m} = 1 \qquad \text{for all } m \tag{10}$$

The MR-CPP has a modified decision variable, x_{ij}^{m}, which designates which truck(s) will cover each arc (i,j), so that there are now m*n integer decision variables in the formulation. The objective function (Equation 5) is the same: minimize total distance traveled by all m trucks. The continuity constraint (Equation 6) is the same flow continuity set, but now they are summed for every truck at each node. Vehicle capacity constraints (Equation 7) enforces vehicle capacity by setting the constant MAXMILES equal to the maximum number of miles each truck may travel. The next two constraint sets (Equation 8) and (Equation 9) are the same as before, but they must also be summed over all the vehicles. The final set of constraints (Equation 10) forces every vehicle to emanate from the common, designated depot.

With the inclusion of subtour elimination constraints and the fact that there are m*n integer variables in this formulation, the MR-CPP becomes even more of a hopeless case as far as an exact solution via mathematical programming is concerned. But this formulation does give one an idea of the complexity and size of exact routing models as more real world or problem constraints are imposed on the problem. Furthermore, an essential dimension of the problem is missing from the MR-CPP, the fact that there are multiple depots in each subdistrict. We feel that at a minimum any design or analysis of routes and their configurations should be done at a subdistrict resolution. A Multi-depot MR-CPP formulation would be a true mess and given the combinatorial explosion we have witnessed at the R-CPP and MR-CPP level, a listing and explanation would be useless at this point.

What has been useful in creating and manipulating these exact formulations is the insights into the problem complexity they have unveiled. So far in our research we have not discovered an efficient method to handle the different road classifications or priorities, given that each route should have class continuity. One way to handle this would be to partition the network into three sub-networks, one for each classification, and run a routing algorithm on each one. This procedure assumes that route continuity is an absolutely binding constraint, which it is not because the current set of IDOH routes violate route continuity. Therefore this topic is better classified as a minor objective, that could possibly be handled with a penalty function. This leads to the point of identifying the true objective of this problem.

The public sector problem of snow and ice control is in reality a multi-objective problem. While minimizing cost, total distance and number of trucks, IDOH also wishes to maximize the level of service to the public. This could be handled with some multi-objective optimization paradigm such as iterative trials holding level of service constant and minimizing cost or maximizing efficiency.

A final point on these exact procedures is that while they are computationally impossible, they do provide the basic groundwork for formal heuristic methods such as linear programming column generation schemes, Lagrangian relaxation procedures, and others. These heuristic methods are appealing because they are based on the exact models and are therefore easy to justify and build the routes up from nothing to near optimal in a logical form.

The previously mentioned heuristic methods design routes from scratch, another viable heuristic approach is to randomly create routes and try to improve them or improve existing routes. Since IDOH has a set of a routes which have historically evolved and were created by experts, a heuristic procedure that tries to improve these existing routes is probably the best approach. Two such methods are a swap/improvement heuristic and a route elimination heuristic.

The swap heuristic answers the basic question: Can the current routes be improved? Indicators of improvement could be less total deadheading, better enforcement of route continuity, greater route compactness, and other factors that only experienced IDOH personnel can provide. A heuristic algorithm of this type requires the network data previously mentioned and the current routes to be digitally encoded in a similar format. It then tries to modify the routes based on the objectives listed above by swapping arcs between routes or cutting down on deadheading. This method results in more efficient and hopefully easier to drive routes which in turn results in a better level of service.

The elimination heuristic answers the question: Do we need all the routes that are currently used to service the network? This method requires the same digitally encoded data as the improvement method. It ranks and sorts the current routes based on total and deadheading length, total number of arcs it covers, and nodes it shares with a route of the same classification. The algorithm would then try to eliminate a route by breaking it up and distributing its arcs among other routes. This method results in fewer needed trucke that are one of the major costs involved in snow and ice control.

3.2 Preliminary Analysis: The Fowler Subdistrict

The methods discussed in the previous section have been investigated using data from the Fowler Subdistrict, the project's test site. At this point in the evolution of this project the aforementioned USGS digital data is still not fully compatible with the routing work of this section, yet it is inherently important to any successful design or analysis previously outlined. To overcome this preliminary incompatibility we have quite crudely created our own digital data with maps and a ruler. This effort has resulted in a 362 arc, 99 node link-node diagram that was hand encoded from a terminal. Therefore at this point it should be stressed that there is no real indicator of the accuracy of this source of data. One limitation of the data is that only those roads currently used by IDOH in snow servicing were considered.

A Chinese Postman Problem formulation was created and run based on the test data. It resulted in a linear program with 362 variables, 99 flow continuity constraints, and an optimal solution of 905.9 lane miles required to service the network (see Appendix A for model listing). Only 2.39 miles were deadheading. Figure 2 represents the flow of information from raw digital data to the output of a mathematical model.

The digital data are currently the hand encoded network. In the future, digital data will be used as described in the following chapter. Network data structures are two inter-linked linked lists of the nodes and arcs and their respective attributes that are created by a program that reads the raw digital data and generates the lists of

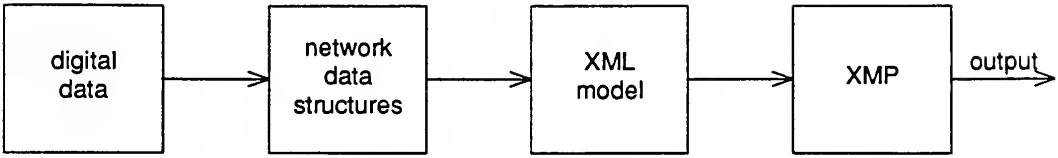


FIGURE 2 - Schematic Representation of Optimization Model

structures. These linked lists of structures can be used to generate a XML model, mathematical program, or feed a heuristic algorithm. Finally XMP is the mathematical programming software which solves the models and generates the results.

The swap/improvement and elimination heuristics were evaluated with hand encoded data and the routes as currently defined by IDOH as the data source. In the process of imposing the IDOH route definitions on the network definition, many shortcomings or conflicts were discovered between the two. While many of the conflicts were resolved by editing the hand encoded data, some still exist which will probably require the actual visitation of the points in question.

The computational effort and routing expertise required for the definition and implementation of the swap/improvement heuristic made its implementation prohibitive in the current project. A very rudimentary elimination heuristic was hand tested with the Fowler data and routes. The result was the elimination of one route, 13-E-1, from unit one's group of routes. In eliminating this route three others, 13-H-2, 13-A-1, 13-F-1, were consequently modified. The removal of route 13-E-1 resulted in a loss of 15.8 deadhead miles and a surplus truck. The three modified routes all stay within the prescriptions set forth in the documented policy, but will need to be evaluated by the appropriate personnel with regard to a realistic implementation. The following table (Table 1) sums up the various methodologies that have been discussed and their respective parameters.

In conclusion, an empirical analysis of the Fowler subdistrict was undertaken to determine the minimum number of routes required to service the network. There are approximately 457 lane miles of class I roads , 271 lane miles of class II roads, and 188 lane miles of class III roads and class I, II, and III routes can not exceed 35, 50, and 65 miles respectively. With the previous given facts the fowler subdistrict should optimally, no deadheading, need 13 class I routes, 6 class II routes, and 3 class III routes or a total of 22 routes. The current IDOH configuration calls for a total of 26 routes or 4 extra routes above the minimum needed. Given the fact that there must exist some dead-heading, a total of 26 routes is not far from a feasible optimal. This comes as no surprise given the fact that each set of routes was designed by a local "expert", in terms of local

Table 1: Methodology Evaluation Parameters

Route Parameters	Current Policy	Theoretical Lower Bound via CPP	Swap Heuristic Improvement	Elimination Heuristic Elimination
Total Required Lane Miles	915.4	903.5	915.4	915.4
Total Deadhead	175.8	2.39	< 175.8	160
Total Lane Miles Serviced	1091.2	905.9	< 1091.2	1075.4
# Routes	26	1	26	25

geography and snow plow routing.

4. DATA CONSIDERATIONS

4.1 The Network Reduction Problem

For the application of vehicle routing over the state highway network, a complete description of the network is required. This description must include all major intersections in each district, adjacency information that indicates which intersections are joined directly by roads, and the lengths of each of these roads. Planning for snow and ice control requires additional information such as the width in lanes of every roadway, and more complete descriptions of intersections, including features such as turn lanes or traffic control devices. Currently the most effective means of assembling such data has been to produce a network by reading the information from a highway map, and then adding additional arcs to the graph to account for multiple lanes. On a statewide basis, this process could prove extremely tedious, with the accuracy of the resulting maps less than desired.

An objective of this research has been to explore available digital map data sources and to find the best methods to convert these data to a usable network representation. One class of geographic data considered is a raster, or grid, format. Data gathered by aerial or satellite photography is in this form. A raster format is impractical for a network application due to the large amount of processing required to extract the roadway information from the data grid. Also, to obtain accurate distances along roads, the sampling size of the raster format must be fairly small, or the errors in calculation would be multiplied many times over.

The most promising format for this application is a vector format. Roadways are represented as polylines, that is, a set of short segments connecting two intersections. Many basic functions would be simplified, especially those of finding adjacent intersections and road lengths. The source for vector data thus far has been the U.S. Geological Survey Digital Line Graph (DLG) format (11). Roadway information is available for the state of Indiana at 1:100000 scale.

The DLG format has some restrictions that could hinder the vehicle routing process. Although the format definition allows roads to be labeled with the number of lanes, no roads in the study area appear to be coded with this information. Detail of intersections is also lacking in the DLG format. For major interchanges on limited access highways, all access roads and ramps are included. For simpler intersections, however, information on right or left turn lanes is not included. One solution to these problems would be to implement an auxiliary database system, which could supply additional information, when necessary in the routing process. Another possible solution would be to include some data from the higher resolution, 1:24000 scale maps which the USGS produces. However, these maps are not currently available in digital form for the entire state, and none is available for the roadway layers in the study area. Finally, the USGS data available are revised infrequently. If a major change to the highway network were implemented, such as a new interstate interchange, or major access roads to a new factory, the data would possibly have to be modified by IDOH staff.

The largest problem with using any digital data representation of the highway network is the sheer amount of information. For example, as supplied, the 7.5 minute quadrangle (approximately 52 square miles) that includes West Lafayette contains 2103 nodes and 3040 lines. A major reason for the large amount of data is the number of city streets not of interest to the IDOH that are included in the map. The same problem arises for rural areas, where county roads are mapped, but should not be part of the routing effort. For the snow and ice control problem, a network consisting only of major roads is necessary. The DLG maps also contain some additional information to define grid lines and edges which can be removed for our application. To address these concerns, a system has been developed to reduce the complexity of the road network represented by the data using the following process:

1. Remove lines that do not represent roads and identify edge nodes for later matching.
2. For adjacent maps, create a minimum cost edge matching to produce a single map. Repeat until one map represents the entire region.
3. Simplify uninteresting intersections, and correct invisible intersections.

4.2 Results of Data Reduction Technique

Figure 3 shows the quadrangle that includes Crawfordsville in the original unfiltered form. All major roads are named within the file by attribute codes. All other roads are marked with a simpler designation, and for this problem, could usually be ignored. For experimental purposes, only state, U.S., and Interstate highways are The first phase of the processing removes these uninteresting roads from the working database. included in the database. To perform a true network analysis over the entire district, many maps would have to be merged into one map. Therefore, the first phase also assigns unique identifiers to every line and node, and identifies edges nodes for later matching. The latter task can be accomplished by using equations to find the distance between a point and a line. If this distance is found from the node to each of the four edges of the map, the minimum of these distances should indicate the edge on which the node lies. After processing the data through this stage, the map of Crawfordsville in Figure 4 is produced.

The second phase of the process is a simple algorithm which links together all of the maps required to represent a region. The header information, which includes the corner points of the map, is read in for both of the maps, and the common edge is identified. All lines in both maps are saved in a temporary file. Nodes which do not lie along the common edge are also written to a temporary file. The remaining nodes are held in two short lists, with a one-to-one correspondence. Iteratively for each node in the first list, the distance by Euclidean metric to every node in the second list is calculated. The minimum value is chosen to be the best possible match. A new "match arc" is created and saved in the temporary file of lines. The edge nodes in question are modified to show the match arc, and are written to the temporary file of nodes. Those nodes are also removed from future consideration as matches. After all nodes have been matched, the new map is assembled from the temporary files, and the phase repeats on two other maps. In worst case, the number of nodes to be matched could result in a possibly inaccurate set of matches. Given the accuracy of the data, and the knowledge that relatively few of the roads represented on the maps are state highways, this process should still be considered efficient.

The third phase, that of removing uninteresting and incorrect intersections, could best be described as an attempt to convert the two dimensional map into a three dimensional model of the highway system. The aim of reducing the number of intersections is to reduce the complexity of the network. Since adjacency information is vital for network analysis problems, a reduction in number of nodes results in a squared reduction in the size of the adjacency matrix. Thus, memory requirements and processing times are likely to drop by the same impressive amount.

The obvious operation of this phase is the removal of unnecessary intersections. As each node is considered, the number of incident arcs is counted. If only two arcs are incident, it is likely that those arcs represent the same road. The attribute lists of the two arcs are compared, and if judged nearly equivalent, the arcs are merged. After suitable bookkeeping is performed, one arc and one node have been removed from the map without loss of information.

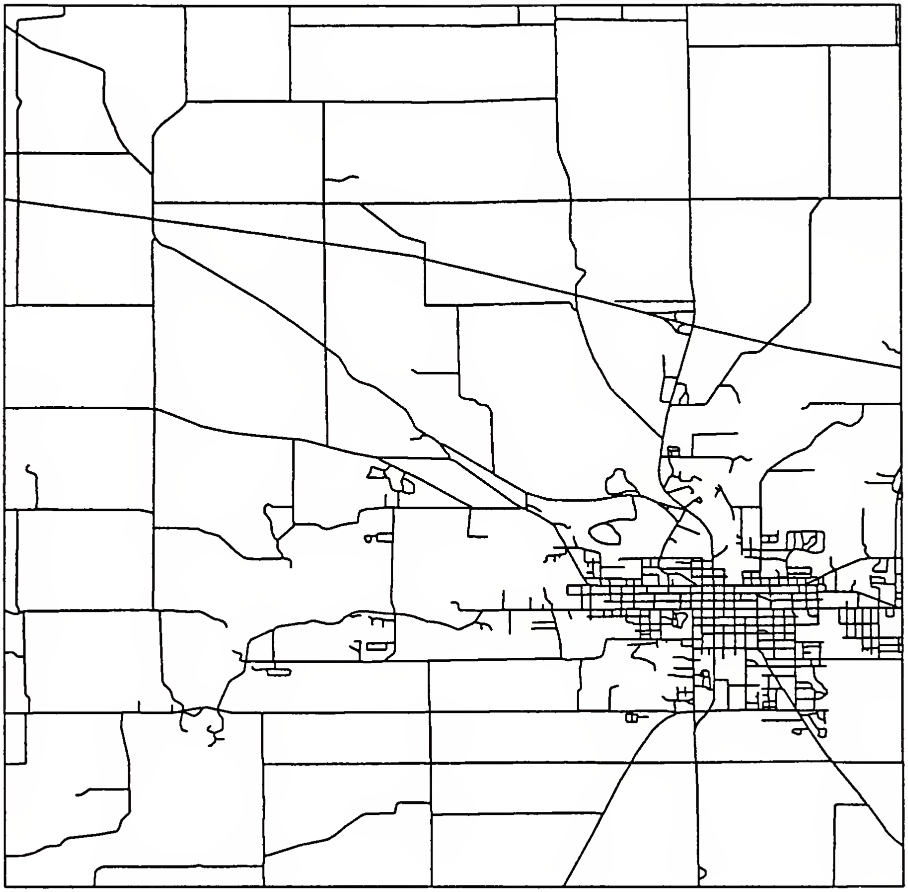


FIGURE 3 - Original USGS map of Crawfordsville roads

The second operation, removing incorrect intersections, is a problem at locations with a road passing over another. To maintain planarity, the DLG map includes an intersection at the crossing of the two roads. The road under the overpass is marked with a special identifying code. To represent the highway network in three dimensions, it is necessary to remove this intersection, while maintaining the sense of the overpassing and underpassing. Since the results of the Phase 3 will appear virtually identical to that of Figure 4, a figure is not included. If nodes were highlighted in these diagrams, an obvious reduction in the number of nodes could be seen.

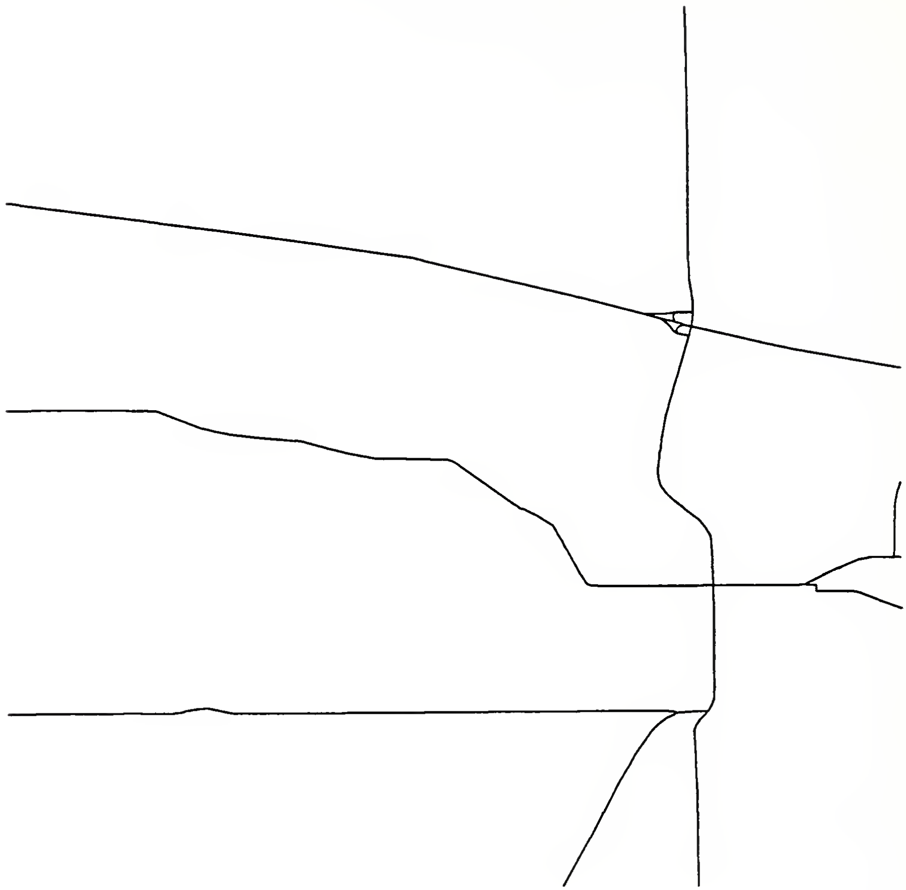


FIGURE 4 - Crawfordsville area following Phase I filtering

The overall results of applying the process to the data of the study area is shown in the map of Figure 5, with a table of the comparative complexities of the map in Table 2. The final map is of a low enough complexity that many exact and heuristic network analysis algorithms can be applied efficiently on many microcomputers.

This process does have limitations for future applications, especially in urban areas. If city streets were included as "interesting" roads, the complexity of the data would not be reduced by as large of a factor. More importantly, the USGS data normally

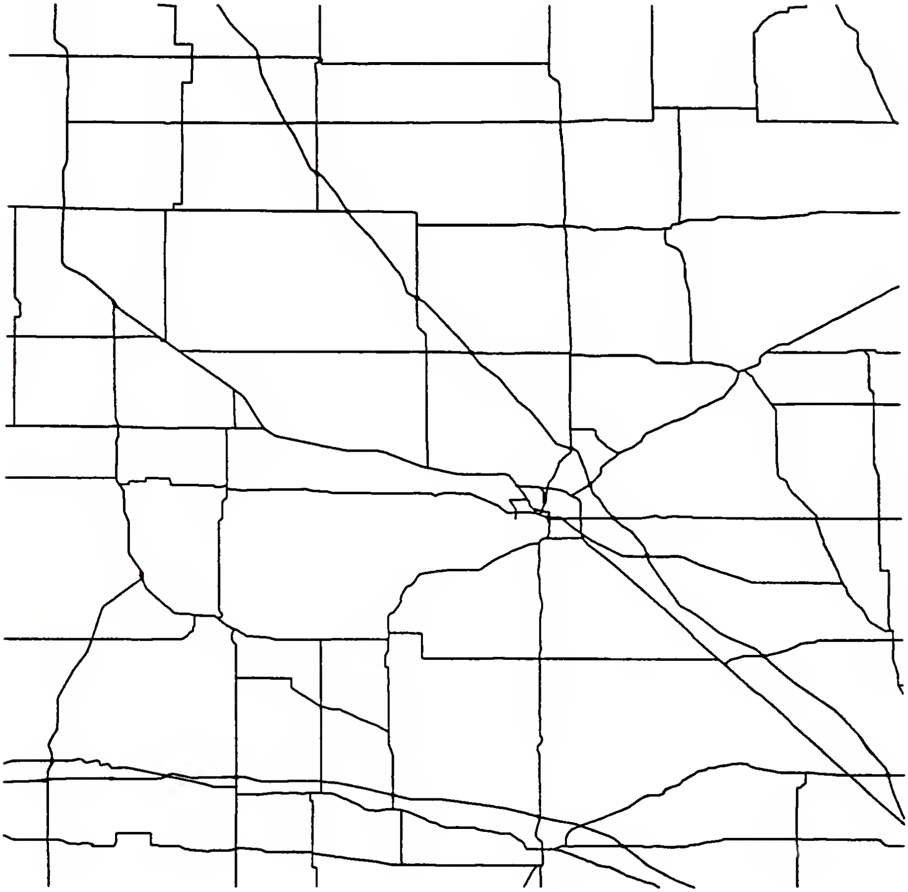


FIGURE 5 - Crawfordsville area following final filtering

labels all minor roads or city streets as "road or street", so all county and farm roads could be considered equivalent to city streets. The most promising method to solve this problem would involve use of city limit information to identify whether a road was in or out of town. Also, the current process does not entirely conform to the IDOH Snow and Ice Removal policy. First, travel roads are not included in this network representation. The most efficient means of including such roads would be to allow the route designer to specify where travel roads would most likely prove beneficial. The routing algorithm

Table 2 - Comparative complexities of maps while being processed

After Phase	Size in Characters	Number of Nodes	Number of Lines
As supplied	6860919	20055	29365
1	1023355	3294	3275
2	1026154	3294	3440
3	285302	452	574

would then reconsider the routes in those areas, and would include those added travel roads if reduced costs would result. Also, the USGS classification of roads does not necessarily match those of the IDOH. Modification of the data, or construction of an auxiliary database could provide corrected class information.

In summary, the process developed makes excellent gains in simplifying the database around which a routing or roadway information system could be developed. Some problems do exist with respect to conforming to IDOH guidelines, and with certain aspects of current vehicle routing. In general, the gains made in data accuracy and reduction in data creation expense should offset these problems.

5. SUMMARY OF THE SNORODES PROTOTYPE

The concepts discussed in the previous chapters have been formalized in the SNOw ROute Design and Evaluation System (SNORODES). The system exists as an interactive graphics-based prototype using modern professional workstation technology. This chapter discusses the design and implementation of the prototype user interface as well as the structure of the design and analysis system. A sample user session is provided as Appendix B to this report.

5.1 The SNORODES Prototype User Interface

For any system designed to represent geographic information, an accurate representation of the environment is essential. To route snow removal vehicles, the most important data would be a representation of the state highway network. Data for the highway system could be acquired by several means such as:

- Manually entering locations of depots and intersections and distances along roads connecting these points
- Digitizing a state road map of the study area
- Acquiring high-resolution digital maps from some third-party

Each of these methods has peculiar advantages and disadvantages.

Entering the data by hand would allow the designer strong control over "map clutter," as only the data for roads requiring service would be inserted into the database. However, the accuracy of these data would be questionable, as reading locations from a map cannot produce the exact location of points. Also, for even a small study area, the data volume required to represent the network could be prohibitive.

An automatic method, such as map digitization, could reduce the effort required to process a map, but many new problems would arise. No digitization method is perfect, so much effort is required to correct the data. Also, many elements, such as divided highways, are represented by more than one line. Use of image processing techniques would be required to reduce this representation to a single line that could be manipulated by a database. Not all road maps could be scanned automatically to produce useful data; the clutter in most maps would prevent some paths from being plotted correctly. This error would result in incorrect distances between intersections, forcing routing algorithms to produce routes with incorrect costs for fuel, abrasive, man-hours, and "deadhead" miles.

The method chosen for this project is maps in the "Digital Line Graph" form from the United States Geological Survey (USGS). Produced from aerial and satellite photographs, these maps provide high accuracy representations of roads, railroads, transmission lines, and rivers (see Table 3). As the maps are available in digital form, already hand checked for accuracy by the USGS, no research time is spent in creating the maps. One major disadvantage of the USGS maps is the tremendous amount of data required to produce a map of a small area. For example, a sample data set near Chattanooga, Tennessee contains over three thousand nodes, and over four thousand line segments. Not only could this massive size cause problems for a database, it would greatly increase the time required to complete routes with existing algorithms. Another drawback of the USGS data form is its infrequent modification. If some major highways were built within a study area, the map data would have to be modified manually, or a special request would be necessary to update the original maps at the USGS. However, the accuracy of the USGS maps, and their availability in digital form far outweigh the disadvantages.

At this stage in the design of the SNORODES system, the primary focus has been on developing an architecture and protocol for a database consisting of a server program that manages the data, and various client programs, such as the graphic interface. This client-server model requires the host computer to operate in a multitasking mode, that is, with many programs sharing the capabilities and resources of the processor virtually simultaneously. The host operating system must also provide some method for interprocess communication. In the prototype system running under the UNIX operating system on a SUN workstation, the "socket" mechanism is used. Any client program can open a connection to the database server, and then request any number of data elements from maps in the study area.

A major limitation of all operating systems is the ceiling on the number of files that can be accessed at any time. In the prototype system, a swapping method is used so that only the most recently used maps are kept in active status. If some inactive map is

Table 3 - Available 1:100,000 USGS Data Elements

Data stored in USGS DLG Maps	
Data Type	**Elements**
Map Header	name locations of corners scale information
Category Header	name number of nodes number of lines number of areas
Node Entry	identification number location number of lines incident directed lines to other nodes number of attributes attribute code pairs
Line Entry	identification number starting node ending node adjacent areas number of segments forming lines line segments number of attributes attribute code pairs

requested, the least recently used map is returned to inactive status, and the newly requested map is made available.

The data can be viewed at any resolution, with a limit placed when all of the available data is displayed in the map display window. The current map resolution is contained in a global map state structure so that the map can be redrawn at any time. Most functions use this structure for reference or update it when changes are made.

A scrolling function that was planned for originally has been replaced by a panning function. This panning function has all of the functionality of scrolling, but allows for movement in two, instead of one, dimensions. The panning is done by asking the user to input two points, the first point is the displayed at the second position, thus translating the data in one or two dimensions. A zooming function was implemented, which allows for either a scaled zoom, based on an input zooming factor. This factor is defined to be always positive with factors less than one being zoom out and those greater than one being zoom in. The zooming function also allows a user to define a square area, by a center and rubber-banding square box, which will display all data contained within the box.

Other display functions include, redraw, dump, grid, and locate. The redraw function does just that, it redraws the map. The dump function does a dump of the map window, in xwd style, so that that map can be dumped to the laser printer (using lwxpr). The grid function places a constant size grid over the data, for reference. The locate function is an unimplemented function, which will allow for database queries, to allow for direct movement to some section of the map.

Newly planned functions include, a display of the current map scale, and a Universal Transverse Mercator (UTM) coordinate display, which will indicate the UTM coordinates of the mouse position.

Currently, stubs (null menu items) have been placed which provide the complete user interface for the unimplemented portions of the project. Although these are not part of the work planned for this course, they do provide some insight into the final functionality of the system. Also implemented is a dynamically displayed menu hierarchy, which will be used for the maintenance management portion of the project.

The entire state of Indiana is available in 1:100,000-scale digital planimetric data corresponding to the USGS 1:100,000-scale map quadrangles. These digital line graphs include data in two categories, hydrograhic and transportation. The data is currently sold only in 30- by 30-minute blocks, making it necessary to purchase two files to cover one 30- by 60-minute quadrangle with the hydrography and transportation layers sold separately. The state is covered by approximately 33 1:100,000-scale map quadrangles or approximately 56 sets of data.

As of January 1, 1988 there were only 19 available or soon to be available digital line graphs from 1:24,000-scale maps out of a total of approximately 700 to cover the entire state. There is no time table for the digitization of data at this resolution, it is done on the basis of demand and project coordination with the U.S. Geological Survey. For example, the state of Connecticut is currently digitized at a resolution of 1:24,000-scale as a result of a state wide geographic information system project that was undertaken for the mutual benefit of the State and Federal government. Therefore unless an adequate and desirable reason arises, for the most part the state of Indiana will remain undigitized at this resolution indefinitely.

5.2 Structure and Function of SNORODES

The preliminary analysis of the problem has yielded the proposed decision support system presented in Figure 6 to aid in the solution of the problem. The database for the system is to be some variation of a geographic information system which is an enhanced spatial database with various analysis tools attached. The "route designer" is a mathematical model which will take the network data as input and output optimal sets of routes to be analyzed. The routes will be passed to a routine that will transform the route parameters such that they can be displayed and manipulated through an interactive routine controlled by the user. By using this interactive interface, the user will be able to test alternative routes by making frequent and rapid changes to the configuration

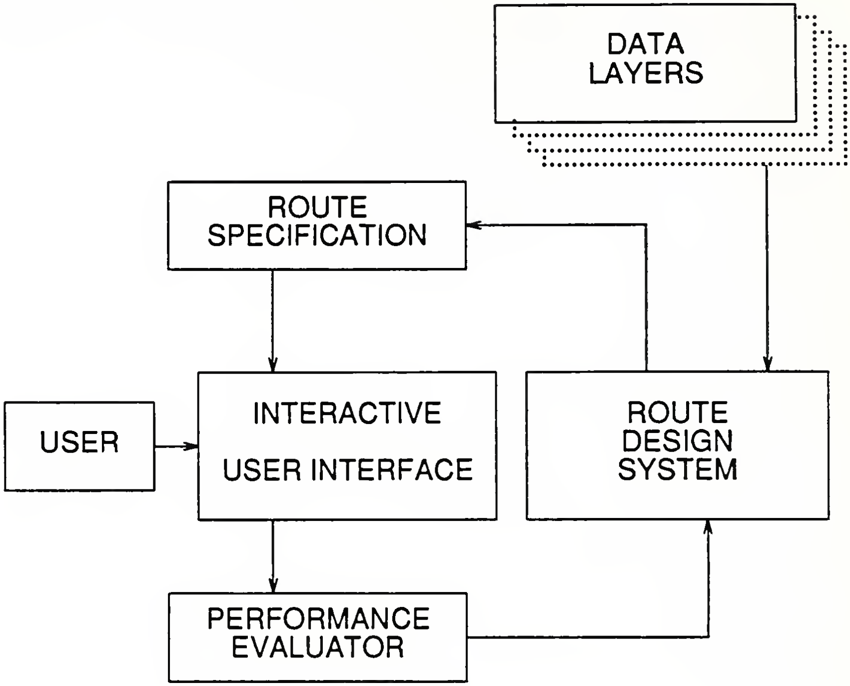


Figure 6: Route Design System Framework

suggested by the model. The resulting route configuration can be evaluated based on performance measures and, if necessary, passed to the route design module for further analysis and modification. The proposed system will reach the best possible solution in a mathematical, network theory or quantitative sense while at the same time involving the user and his/her special knowledge with regard to the local area and constraints via its interactive and iterative solution procedure. The remainder of this section discusses the possible application of fuzzy set theory for two components of the system, the math model and the knowledge-based decision support module.

The mathematical model is responsible for generating sets of optimal routes given the network and problem constraints. The network may be viewed as a collection of arcs (roads) and nodes (intersections or turnarounds) with their respective attributes and connectivity included. Some of these attributes are road width, directional sense, and classification or priority rating. These classifications or priority ratings have been discretized into three crisp sets based on the road type and traffic volume with class one roads having the highest service priority; continuous service during a storm. One objective of this research is to examine the highway department's current policy with regard to the entire snow removal operation and make recommendations for possible revisions that will improve efficiency without sacrificing a given minimal level of service. This road priority scheme may be one area that could benefit from a fuzzy approach.

The highway department claims that there are many exceptions to the current classification scheme based on based on local importance of a particular road due to such factors as emergency service facilities (eg. hospitals, fire stations, etc.) located on a lower class road. Conditions such as these cause the local decision makers to request a change of classification. The author proposes the possibility of making roadway importance a fuzzy variable based on the policy specifications and special local knowledge. This would relax the limiting three class scheme and create a more realistic parameter for a roadway's importance. This in turn would insert a qualitative or human judgemental element into a very quantitatively assuming model.

Furthermore, the mathematical model is to be formulated as a variant of an arc or node covering linear program with multiple objectives; minimizing "deadhead" miles and cost while maximizing the level of service. The arc or node covering formulations are known as the "Chinese Postman problem" and the "Traveling Salesman problem" respectively. Both of these algorithms have been thoroughly researched and covered in the literature, but the snow removal problem presents some special problems for them. These problems, multiple vehicles and passes on an arc, and the dynamic and individual characteristics of each storm, can be considered special cases of the previously mentioned algorithms that induce additional constraints and complicate the network formulation. This could lead to an overconstrained or unsolvable problem. At this point simplifying assumptions are sometimes made so as to avoid trying to quantify and formulate constraints for qualitative and imprecise problem parameters such as: truck speed, storm severity, arc type and time to clear it. The theory of fuzzy sets applied to network theory and linear programming could help deal with these imprecise and qualitative modeling constraints.

The knowledge-based decision support or analysis module in the system is to be designed to help judge and design the routes with the user. Recently there has been a tremendous amount of research, literature, and hype surrounding the development and application of knowledge-based or expert systems and their potential role in engineering decision making. This role is in the area of how these systems represent uncertainty and infer solutions from the knowledge they contain and is input. This part of the system will receive a set of routes and performance indicators that the decision support module must analyze and judge with the help of the user and his/her opinion. One point that should be made is the importance of analyzing the type of knowledge and logical inference that takes place in any particular problem when using an expert system technology. There are a wide variety of tools and methodologies available for development work in this area and the more cerebral aspects of inference and uncertainty propagation can easily be taken for granted in a higher level tool. This could be dangerous because some problems may not be well suited for a particular tool. That is, one may be able to force his/her problem to fit into the scheme of the tool and get solutions, but those solutions may not be completely valid because of the previously mentioned uncertainty and inference logic.

6. DIRECTIONS FOR FUTURE RESEARCH

This research has demonstrated the feasibility of constructing a route design and analysis system for highway maintenance and service activities such as wintertime snow and ice control. The following specific tasks would be needed to implement such a system for the State of Indiana:

1. Establishment of a compter platform sufficient to support the interactive graphics and numerical computation necessary to perform automated mapping functions.
2. Acquisition of statewide data from the USGS which are presently available in digital form.
3. Conversion of USGS transportation data to state resolution using the methods discussed in Chapter 4.
4. Further development of the SNORODES user interface with new provisions for network data editing and color enhancement of route information including the capability of producing hard-copy color maps.
5. Implementation of the SNORODES analysis system as discussed in Chapter 3 of this report and described further in Chapter 5 as necessary.
6. Training of IDOH personnel in the use of the system.
7. Exposure of the final system to IDOH engineers in an attempt to identify other route oriented activities that might take advantage of this unique and powerful technology.

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APPENDIX A - Code for Optimization Model

88/10/02
16:01:27

Sample Xmp Input Format code

1

```
$ CPP


$ VARIABLES

X1   X2   X3   X4   X5   X6   X7   X8   X9
X10  X11  X12  X13  X14  X15  X16  X17  X18
X19  X20  X21  X22  X23  X24  X25  X26  X27
X28  X29  X30  X31  X32  X33  X34  X35  X36
X37  X38  X39  X40  X41  X42  X43  X44  X45
X46  X47  X48  X49  X50  X51  X52  X53  X54
X55  X56  X57  X58  X59  X60  X61  X62  X63
X64  X65  X66  X67  X68  X69  X70  X71  X72
X73  X74  X75  X76  X77  X78  X79  X80  X81
X82  X83  X84  X85  X86  X87  X88  X89  X90
X91  X92  X93  X94  X95  X96  X97  X98  X99
X100  X101  X102  X103  X104  X105  X106  X107  X108
X109  X110  X111  X112  X113  X114  X115  X116  X117
X118  X119  X120  X121  X122  X123  X124  X125  X126
X127  X128  X129  X130  X131  X132  X133  X134  X135
X136  X137  X138  X139  X140  X141  X142  X143  X144
X145  X146  X147  X148  X149  X150  X151  X152  X153
X154  X155  X156  X157  X158  X159  X160  X161  X162
X163  X164  X165  X166  X167  X168  X169  X170  X171
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X334  X335  X336  X337  X338  X339  X340  X341  X342
X343  X344  X345  X346  X347  X348  X349  X350  X351
X352  X353  X354  X355  X356  X357  X358  X359  X360
X361  X362

$ EQUATIONS

EQ1 .. + X1 + X7 + X8
       - X2 - X9 - X10
       =E= 0
EQ2 .. + X2 + X6
       - X3 - X5
       =E= 0
EQ3 .. + X4 + X5 + X15
       - X1 - X6 - X16
       =E= 0
EQ4 .. + X3 + X9 + X10 + X13 + X14
       - X4 - X7 - X8 - X11 - X12
       =E= 0
EQ5 .. + X16 + X37 + X38
       - X15 - X39 - X40
       =E= 0
EQ6 .. + X39 + X40 + X33 + X34 + X41 + X42 + X78

       - X35 - X36 - X37 - X38 - X43 - X44 - X77

       =E= 0
EQ7 .. + X11 + X12 + X18 + X25 + X26
       - X13 - X14 - X17 - X27 - X28
       =E= 0
EQ8 .. + X19 + X21 + X22 + X35 + X36
       - X18 - X23 - X24 - X33 - X34
       =E= 0
EQ9 .. + X17 + X23 + X24
       - X20 - X21 - X22
       =E= 0
EQ10 .. + X20 + X27 + X28 + X29 + X30
        - X19 - X25 - X26 - X31 - X32
        =E= 0
EQ11 .. + X43 + X44 + X73 + X74 + X57 + X58
        - X75 - X76 - X41 - X42 - X59 - X60
        =E= 0
EQ12 .. + X31 + X32 + X45 + X53 + X54
        - X29 - X30 - X55 - X56 - X46
        =E= 0
EQ13 .. + X59 + X60 + X49 + X50 + X48
        - X57 - X58 - X45 - X51 - X52
        =E= 0
EQ14 .. + X51 + X52 + X46 + X61
        - X49 - X50 - X47 - X62
        =E= 0
EQ15 .. + X55 + X56 + X47 + X69 + X70
        - X53 - X54 - X48 - X71 - X72
        =E= 0
EQ16 .. + X62 + X63 + X67
        - X61 - X64 - X68
        =E= 0
EQ17 .. + X64 + X65
        - X63 - X66
        =E= 0
EQ18 .. + X143 + X142 + X156
        - X141 - X144 - X155
        =E= 0
EQ19 .. + X155 + X160 + X158
        - X156 - X157 - X159
        =E= 0
EQ20 .. + X159 + X161 + X169 + X170
        - X160 - X162 - X171 - X172
        =E= 0
EQ21 .. + X162 + X165 + X166 + X71 + X72
        - X69 - X70 - X167 - X168 - X163
        =E= 0
EQ22 .. + X163 + X171 + X172 + X173
        - X169 - X170 - X164 - X174
        =E= 0
EQ23 .. + X164 + X167 + X168 + X177 + X178
        - X161 - X165 - X166 - X179 - X180
        =E= 0
EQ24 .. + X68 + X174 + X175
        - X67 - X173 - X176
        =E= 0
EQ25 .. + X66 + X176 + X182
        - X65 - X175 - X181
        =E= 0
```

Sample Xmp Input Format
code


```
EQ26 .. + X179 + X180 + X185 + X189 + X190
        - X177 - X178 - X183 - X191 - X192
        =E= 0
EQ27 .. + X186 + X187 + X242
        - X185 - X188 - X241
        =E= 0
EQ28 .. + X183 + X188 + X181
        - X182 - X184 - X187
        =E= 0
EQ29 .. + X184 + X191 + X192 + X193 + X194
        - X186 - X189 - X190 - X195 - X196
        =E= 0
EQ30 .. + X195 + X196 + X197 + X205 + X206
        - X193 - X194 - X200 - X207 - X208
        =E= 0
EQ31 .. + X198 + X201 + X202 + X240
        - X197 - X203 - X204 - X239
        =E= 0
EQ32 .. + X200 + X203 + X204
        - X199 - X201 - X202
        =E= 0
EQ33 .. + X199 + X207 + X208 + X209 + X210
        - X198 - X205 - X206 - X211 - X212
        =E= 0
EQ34 .. + X211 + X212 + X213 + X217 + X218
        - X209 - X210 - X214 - X219 - X220
        =E= 0
EQ35 .. + X215 + X221 + X222 + X225
        - X213 - X223 - X224 - X226
        =E= 0
EQ36 .. + X216 + X219 + X220
        - X215 - X217 - X218
        =E= 0
EQ37 .. + X214 + X223 + X224
        - X216 - X221 - X222
        =E= 0
EQ38 .. + X239 + X241 + X244 + X276
        - X240 - X242 - X243 - X275
        =E= 0
EQ39 .. + X275 + X301 + X302 + X303 + X304
        - X276 - X299 - X300 - X305 - X306
        =E= 0
EQ40 .. + X305 + X306 + X307 + X308
        - X303 - X304 - X153 - X154 - X311 - X312
        =E= 0
EQ41 .. + X151 + X152 + X313 + X314
        - X307 - X308
        =E= 0
EQ42 .. + X144 + X145 + X147
        - X143 - X146 - X148
        =E= 0
EQ43 .. + X75 + X76 + X148 + X149 + X153 + X154
        - X73 - X74 - X147 - X150 - X151 - X152
        =E= 0
EQ44 .. + X140 + X146 + X150
        - X139 - X145 - X149
        =E= 0
EQ45 .. + X135 + X136 + X312 + X311 + X315
        - X137 - X138 - X313 - X314 - X316
        =E= 0
EQ46 .. + X316 + X318
        - X315 - X317
        =E= 0
EQ47 .. + X134 + X317 + X319 + X322
        - X133 - X318 - X320 - X321
        =E= 0
EQ48 .. + X320
        - X319
        =E= 0
EQ49 .. + X129 + X130 + X133
        - X131 - X132 - X134
        =E= 0
EQ50 .. + X111 + X112 + X137 + X138 + X120
        - X113 - X114 - X119 - X135 - X136
        =E= 0
EQ51 .. + X105 + X106 + X119 + X131 + X132
        - X107 - X108 - X120 - X129 - X130
        =E= 0
EQ52 .. + X141 + X139 + X127 + X128
        - X142 - X140 - X125 - X126
        =E= 0
EQ53 .. + X125 + X126 + X123 + X124 + X109
        - X127 - X128 - X121 - X122
        =E= 0
EQ54 .. + X121 + X122 + X115 + X116
        - X110 - X123 - X124 - X117 - X118
        =E= 0
EQ55 .. + X95 + X96 + X117 + X118 + X107 + X108
        - X93 - X94 - X115 - X116 - X105 - X106
        =E= 0
EQ56 .. + X99 + X100 + X103 + X104
        - X101 - X102 - X97 - X98
        =E= 0
EQ57 .. + X89 + X90 + X97 + X98
        - X95 - X96 - X91 - X92
        =E= 0
EQ58 .. + X77 + X87 + X88
        - X89 - X90 - X99 - X100
        =E= 0
EQ59 .. + X91 + X92 + X93 + X94
        - X85 - X86 - X83 - X84
        =E= 0
EQ60 .. + X85 + X86 + X81 + X82
        - X78 - X87 - X88
        =E= 0
EQ61 .. + X83 + X84 + X80
        - X79 - X81 - X82
        =E= 0
EQ62 .. + X79
        - X80
        =E= 0
EQ63 .. + X328
        - X327
        =E= 0
EQ64 .. + X327 + X325 + X330
        - X326 - X329 - X328
        =E= 0
EQ65 .. + X329 + X332 + X334
        - X330 - X331 - X333
        =E= 0
EQ66 .. + X333 + X336 + X338
        - X334 - X335 - X337
        =E= 0
EQ67 .. + X337 + X340 + X341 + X342
        - X343 - X344 - X339 - X338
        =E= 0
EQ68 .. + X339
        - X340
```

Sample Xmp Input Format

code


```
        =E= 0
EQ69 .. + X335
        - X336
        =E= 0
EQ70 .. + X346 + X309
        - X347 - X345
        =E= 0
EQ71 .. + X331 + X355 + X349
        - X348 - X332 - X354
        =E= 0
EQ72 .. + X343 + X344 + X348
        - X352 - X353
        =E= 0
EQ73 .. + X350 + X351
        - X349 - X341 - X342
        =E= 0
EQ74 .. + X360 + X361 + X352 + X353 + X356
        - X362 - X310 - X350 - X351 - X357
        =E= 0
EQ75 .. + X357 + X358
        - X359 - X356
        =E= 0
EQ76 .. + X359
        - X358
        =E= 0
EQ77 .. + X289 + X290 + X347 + X297 + X362 + X310
        - X291 - X292 - X346 - X298 - X360 - X361
        =E= 0
EQ78 .. + X293 + X298 + X326 + X323
        - X294 - X297 - X325 - X324
        =E= 0
EQ79 .. + X324 + X321
        - X323 - X322
        =E= 0
EQ80 .. + X285 + X265 + X284
        - X286 - X266 - X283
        =E= 0
EQ81 .. + X267 + X268 + X291 + X292 + X287 + X286
        - X269 - X270 - X289 - X290 - X285 - X288
        =E= 0
EQ82 .. + X277 + X288 + X294 + X295
        - X278 - X287 - X293 - X296
        =E= 0
EQ83 .. + X281 + X282 + X299 + X300 + X296
        - X279 - X280 - X301 - X302 - X295
        =E= 0
EQ84 .. + X279 + X280 + X273 + X274 + X278
        - X271 - X272 - X281 - X282 - X277
        =E= 0
EQ85 .. + X263
        - X264
        =E= 0
EQ86 .. + X231 + X264 + X266 + X261
        - X232 - X263 - X265 - X262
        =E= 0
EQ87 .. + X257 + X258 + X269 + X270 + X262 + X255
        - X259 - X260 - X267 - X268 - X261 - X256
        =E= 0
EQ88 .. + X249 + X250 + X271 + X272 + X256 + X243 + X253

        - X251 - X252 - X255 - X274 - X273 - X244 - X254

        =E= 0
EQ89 .. + X245 + X246 + X251 + X252 + X238
        - X237 - X247 - X248 - X249 - X250
        =E= 0
EQ90 .. + X235 + X236 + X247 + X248 + X259 + X260
        - X233 - X234 - X245 - X246 - X257 - X258
        =E= 0
EQ91 .. + X230 + X232
        - X229 - X231
        =E= 0
EQ92 .. + X229 + X228 + X233 + X234
        - X227 - X230 - X235 - X236
        =E= 0
EQ93 .. + X227 + X226 + X237
        - X225 - X238 - X228
        =E= 0
EQ94 .. + X101 + X102
        - X109 - X111 - X112
        =E= 0
EQ95 .. + X110 + X113 + X114
        - X103 - X104
        =E= 0
EQ96 .. + X283 + X345
        - X309 - X284
        =E= 0
EQ97 .. + X354
        - X355
        =E= 0
EQ98 .. + X254
        - X253
        =E= 0
EQ99 .. + X157
        - X158
        =E= 0

COST .. + 0.25 X1 + 0.25 X2 + 0.25 X3 + 0.25 X4 + 0.19 X5
        + 0.19 X6 + 0.25 X7 + 0.25 X8 + 0.25 X9 + 0.25 X10
        + 3.13 X11 + 3.13 X12 + 3.13 X13 + 3.13 X14 + 4.50 X15
        + 4.50 X16 + 0.13 X17 + 0.19 X18 + 0.13 X19 + 0.19 X20
        + 0.16 X21 + 0.16 X22 + 0.16 X23 + 0.16 X24 + 0.31 X25
        + 0.31 X26 + 0.31 X27 + 0.31 X28 + 2.56 X29 + 2.56 X30
        + 2.56 X31 + 2.56 X32 + 1.88 X33 + 1.88 X34 + 1.88 X35
        + 1.88 X36 + 1.19 X37 + 1.19 X38 + 1.19 X39 + 1.19 X40
        + 2.06 X41 + 2.06 X42 + 2.06 X43 + 2.06 X44 + 0.19 X45
        + 0.19 X46 + 0.19 X47 + 0.19 X48 + 0.13 X49 + 0.13 X50
        + 0.13 X51 + 0.13 X52 + 0.31 X53 + 0.31 X54 + 0.31 X55
        + 0.31 X56 + 1.31 X57 + 1.31 X58 + 1.31 X59 + 1.31 X60
        + 3.13 X61 + 3.13 X62 + 10.00 X63 + 10.00 X64 + 10.31 X65
        + 10.31 X66 + 3.75 X67 + 3.75 X68 + 2.88 X69 + 2.88 X70
        + 2.88 X71 + 2.88 X72 + 2.06 X73 + 2.06 X74 + 2.06 X75
        + 2.06 X76 + 1.88 X77 + 1.88 X78 + 1.30 X79 + 1.30 X80
        + 0.22 X81 + 0.22 X82 + 0.28 X83 + 0.28 X84 + 0.08 X85
        + 0.08 X86 + 0.08 X87 + 0.08 X88 + 0.08 X89 + 0.08 X90
        + 0.08 X91 + 0.08 X92 + 0.63 X93 + 0.63 X94 + 0.54 X95
        + 0.54 X96 + 0.39 X97 + 0.39 X98 + 0.39 X99 + 0.39 X100
        + 0.33 X101 + 0.33 X102 + 0.33 X103 + 0.33 X104 + 0.24 X105
        + 0.24 X106 + 0.24 X107 + 0.24 X108 + 0.15 X109 + 0.15 X110
        + 0.60 X111 + 0.60 X112 + 0.52 X113 + 0.52 X114 + 0.16 X115
        + 0.16 X116 + 0.16 X117 + 0.16 X118 + 0.18 X119 + 0.18 X120
        + 0.19 X121 + 0.19 X122 + 0.19 X123 + 0.19 X124 + 0.54 X125
        + 0.54 X126 + 0.54 X127 + 0.54 X128 + 0.45 X129 + 0.45 X130
        + 0.45 X131 + 0.45 X132 + 0.75 X133 + 0.75 X134 + 0.90 X135
        + 0.90 X136 + 0.90 X137 + 0.90 X138 + 1.27 X139 + 1.27 X140
        + 3.43 X141 + 3.43 X142 + 2.60 X143 + 2.60 X144 + 0.15 X145
        + 0.15 X146 + 0.15 X147 + 0.15 X148 + 0.30 X149 + 0.30 X150
        + 1.05 X151 + 1.05 X152 + 1.27 X153 + 1.27 X154 + 1.04 X155
```

```
     + 1.04 X156 + 0.00 X157 + 0.00 X158 + 0.21 X159 + 0.21 X160
     + 0.25 X161 + 0.19 X162 + 0.19 X163 + 0.13 X164 + 0.31 X165
     + 0.31 X166 + 0.31 X167 + 0.31 X168 + 0.19 X169 + 0.19 X170
     + 0.19 X171 + 0.19 X172 + 1.38 X173 + 1.38 X174 + 5.88 X175
     + 5.88 X176 + 9.38 X177 + 9.38 X178 + 9.38 X179 + 9.38 X180
     + 5.75 X181 + 5.75 X182 + 0.19 X183 + 0.19 X184 + 0.25 X185
     + 0.13 X186 + 0.19 X187 + 0.19 X188 + 0.38 X189 + 0.38 X190
     + 0.38 X191 + 0.38 X192 + 5.00 X193 + 5.00 X194 + 5.00 X195
     + 5.00 X196 + 0.30 X197 + 0.15 X198 + 0.30 X199 + 0.16 X200
     + 0.15 X201 + 0.15 X202 + 0.15 X203 + 0.15 X204 + 0.45 X205
     + 0.45 X206 + 0.45 X207 + 0.45 X208 + 7.81 X209 + 7.81 X210
     + 7.81 X211 + 7.81 X212 + 0.19 X213 + 0.26 X214 + 0.13 X215
     + 0.19 X216 + 0.38 X217 + 0.38 X218 + 0.38 X219 + 0.38 X220
     + 0.16 X221 + 0.16 X222 + 0.16 X223 + 0.16 X224 + 10.75 X225
     + 10.75 X226 + 6.00 X227 + 6.00 X228 + 2.81 X229 + 2.81 X230
     + 10.56 X231 + 10.56 X232 + 8.75 X233 + 8.75 X234 + 8.75 X235
     + 8.75 X236 + 10.25 X237 + 10.25 X238 + 4.31 X239 + 4.31 X240
     + 2.63 X241 + 2.63 X242 + 14.56 X243 + 14.56 X244 + 4.25 X245
     + 4.25 X246 + 4.25 X247 + 4.25 X248 + 1.19 X249 + 1.19 X250
     + 1.19 X251 + 1.19 X252 + 0.00 X253 + 0.00 X254 + 3.25 X255
     + 3.25 X256 + 2.75 X257 + 2.57 X258 + 2.57 X259 + 2.57 X260
     + 5.81 X261 + 5.81 X262 + 1.88 X263 + 1.88 X264 + 7.06 X265
     + 7.06 X266 + 7.13 X267 + 7.13 X268 + 7.13 X269 + 7.13 X270
     + 4.38 X271 + 4.38 X272 + 4.38 X273 + 4.38 X274 + 9.75 X275
     + 9.75 X276 + 3.06 X277 + 3.06 X278 + 3.44 X279 + 3.44 X280
     + 3.44 X281 + 3.44 X282 + 3.13 X283 + 3.13 X284 + 6.06 X285
     + 6.06 X286 + 6.63 X287 + 6.63 X288 + 4.13 X289 + 4.13 X290
     + 4.13 X291 + 4.13 X292 + 4.50 X293 + 4.50 X294 + 2.00 X295
     + 2.00 X296 + 7.38 X297 + 7.38 X298 + 10.63 X299 + 10.63 X300
     + 10.63 X301 + 10.63 X302 + 5.56 X303 + 5.56 X304 + 5.56 X305
     + 5.56 X306 + 0.22 X307 + 0.22 X308 + 2.56 X309 + 7.13 X310
     + 1.57 X311 + 1.57 X312 + 0.97 X313 + 0.97 X314 + 1.06 X315
     + 1.06 X316 + 1.05 X317 + 1.05 X318 + 0.52 X319 + 0.52 X320
     + 4.48 X321 + 4.48 X322 + 12.81 X323 + 12.81 X324 + 10.19 X325
     + 10.19 X326 + 1.25 X327 + 1.25 X328 + 1.44 X329 + 1.44 X330
     + 4.13 X331 + 4.13 X332 + 6.56 X333 + 6.56 X334 + 2.81 X335
     + 2.81 X336 + 0.94 X337 + 0.94 X338 + 6.69 X339 + 6.69 X340
     + 6.25 X341 + 6.25 X342 + 6.00 X343 + 6.00 X344 + 2.56 X345
     + 7.94 X346 + 7.94 X347 + 0.94 X348 + 0.89 X349 + 0.38 X350
     + 0.38 X351 + 0.56 X352 + 0.56 X353 + 0.40 X354 + 0.40 X355
     + 0.31 X356 + 0.31 X357 + 5.31 X358 + 5.31 X359 + 7.13 X360
     + 7.13 X361 + 7.13 X362
     =N=

5 BOUNDS

X1 =G= 1
X2 =G= 1
X3 =G= 1
X4 =G= 1
X5 =G= 1
X6 =G= 1
X7 =G= 1
X8 =G= 1
X9 =G= 1
X10 =G= 1
X11 =G= 1
X12 =G= 1
X13 =G= 1
X14 =G= 1
X15 =G= 1
X16 =G= 1
X17 =G= 1
X18 =G= 1
X19 =G= 1
X20 =G= 1
X21 =G= 1
X22 =G= 1
X23 =G= 1
X24 =G= 1
X25 =G= 1
X26 =G= 1
X27 =G= 1
X28 =G= 1
X29 =G= 1
X30 =G= 1
X31 =G= 1
X32 =G= 1
X33 =G= 1
X34 =G= 1
X35 =G= 1
X36 =G= 1
X37 =G= 1
X38 =G= 1
X39 =G= 1
X40 =G= 1
X41 =G= 1
X42 =G= 1
X43 =G= 1
X44 =G= 1
X45 =G= 1
X46 =G= 1
X47 =G= 1
X48 =G= 1
X49 =G= 1
X50 =G= 1
X51 =G= 1
X52 =G= 1
X53 =G= 1
X54 =G= 1
X55 =G= 1
X56 =G= 1
X57 =G= 1
X58 =G= 1
X59 =G= 1
X60 =G= 1
X61 =G= 1
X62 =G= 1
X63 =G= 1
X64 =G= 1
X67 =G= 1
X68 =G= 1
X69 =G= 1
X70 =G= 1
X71 =G= 1
X72 =G= 1
X73 =G= 1
X74 =G= 1
X75 =G= 1
X76 =G= 1
X79 =G= 1
X80 =G= 1
X81 =G= 1
X82 =G= 1
X83 =G= 1
X84 =G= 1
X85 =G= 1
X86 =G= 1
```

88/10/02
16:01:27

Sample Xmp Input Format
code

5

```
X87 =G= 1
X88 =G= 1
X89 =G= 1
X90 =G= 1
X91 =G= 1
X92 =G= 1
X93 =G= 1
X94 =G= 1
X95 =G= 1
X96 =G= 1
X97 =G= 1
X98 =G= 1
X99 =G= 1
X100 =G= 1
X101 =G= 1
X102 =G= 1
X103 =G= 1
X104 =G= 1
X105 =G= 1
X106 =G= 1
X107 =G= 1
X108 =G= 1
X109 =G= 1
X110 =G= 1
X111 =G= 1
X112 =G= 1
X113 =G= 1
X114 =G= 1
X115 =G= 1
X116 =G= 1
X117 =G= 1
X118 =G= 1
X119 =G= 1
X120 =G= 1
X121 =G= 1
X122 =G= 1
X123 =G= 1
X124 =G= 1
X125 =G= 1
X126 =G= 1
X127 =G= 1
X128 =G= 1
X129 =G= 1
X130 =G= 1
X131 =G= 1
X132 =G= 1
X133 =G= 1
X134 =G= 1
X135 =G= 1
X136 =G= 1
X137 =G= 1
X138 =G= 1
X139 =G= 1
X140 =G= 1
X141 =G= 1
X142 =G= 1
X145 =G= 1
X146 =G= 1
X147 =G= 1
X148 =G= 1
X149 =G= 1
X150 =G= 1
X151 =G= 1
X152 =G= 1
X153 =G= 1
X154 =G= 1
X155 =G= 1
X156 =G= 1
X157 =G= 1
X158 =G= 1
X159 =G= 1
X160 =G= 1
X161 =G= 1
X162 =G= 1
X163 =G= 1
X164 =G= 1
X165 =G= 1
X166 =G= 1
X167 =G= 1
X168 =G= 1
X169 =G= 1
X170 =G= 1
X171 =G= 1
X172 =G= 1
X173 =G= 1
X174 =G= 1
X175 =G= 1
X176 =G= 1
X177 =G= 1
X178 =G= 1
X179 =G= 1
X180 =G= 1
X181 =G= 1
X182 =G= 1
X183 =G= 1
X184 =G= 1
X185 =G= 1
X186 =G= 1
X187 =G= 1
X188 =G= 1
X189 =G= 1
X190 =G= 1
X191 =G= 1
X192 =G= 1
X193 =G= 1
X194 =G= 1
X195 =G= 1
X196 =G= 1
X197 =G= 1
X198 =G= 1
X199 =G= 1
X200 =G= 1
X201 =G= 1
X202 =G= 1
X203 =G= 1
X204 =G= 1
X205 =G= 1
X206 =G= 1
X207 =G= 1
X208 =G= 1
X209 =G= 1
X210 =G= 1
X211 =G= 1
X212 =G= 1
X213 =G= 1
X214 =G= 1
X215 =G= 1
X216 =G= 1
```

Sample Xmp Input Format code


```
X217 =G= 1
X218 =G= 1
X219 =G= 1
X220 =G= 1
X221 =G= 1
X222 =G= 1
X223 =G= 1
X224 =G= 1
X231 =G= 1
X232 =G= 1
X233 =G= 1
X234 =G= 1
X235 =G= 1
X236 =G= 1
X237 =G= 1
X238 =G= 1
X239 =G= 1
X240 =G= 1
X241 =G= 1
X242 =G= 1
X243 =G= 1
X244 =G= 1
X245 =G= 1
X246 =G= 1
X247 =G= 1
X248 =G= 1
X249 =G= 1
X250 =G= 1
X251 =G= 1
X252 =G= 1
X253 =G= 1
X254 =G= 1
X255 =G= 1
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X257 =G= 1
X258 =G= 1
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X286 =G= 1
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X350 =G= 1
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X355 =G= 1
X356 =G= 1
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X361 =G= 1
X362 =G= 1

$ END
```
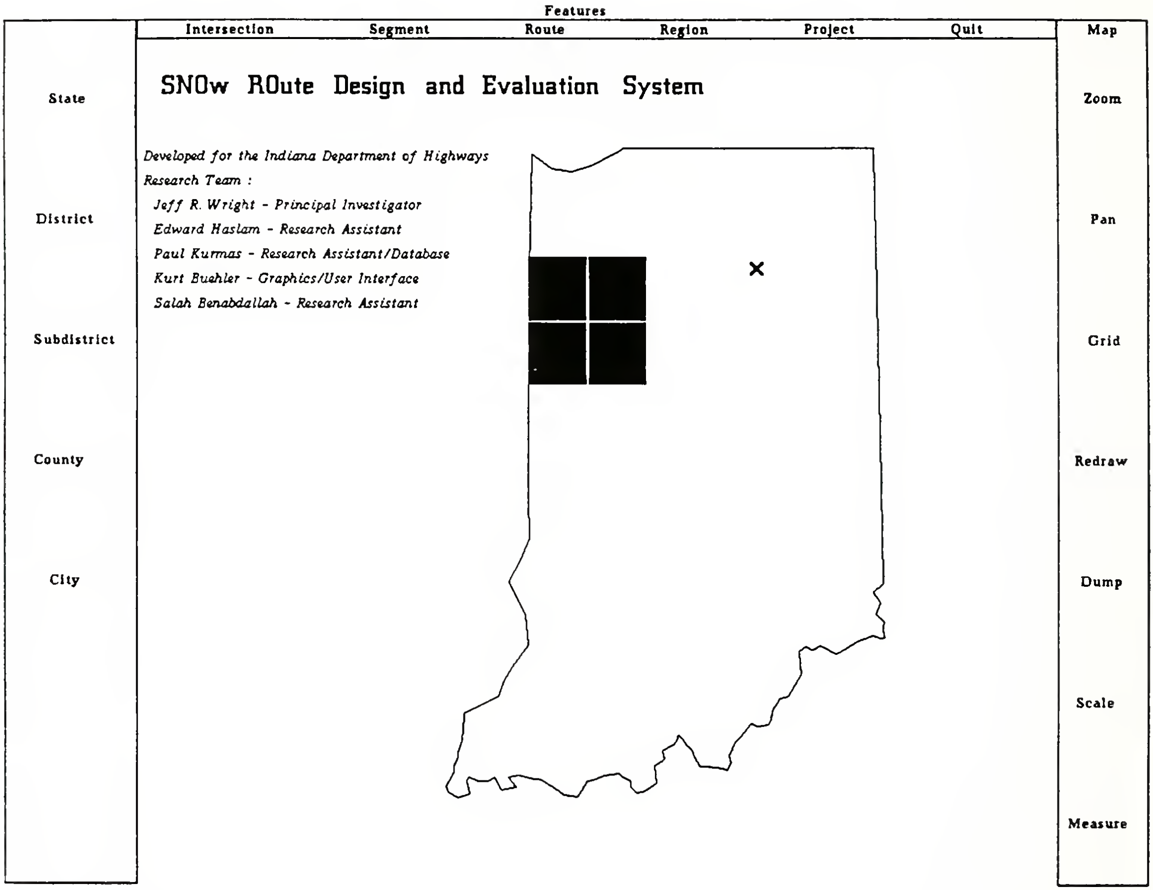
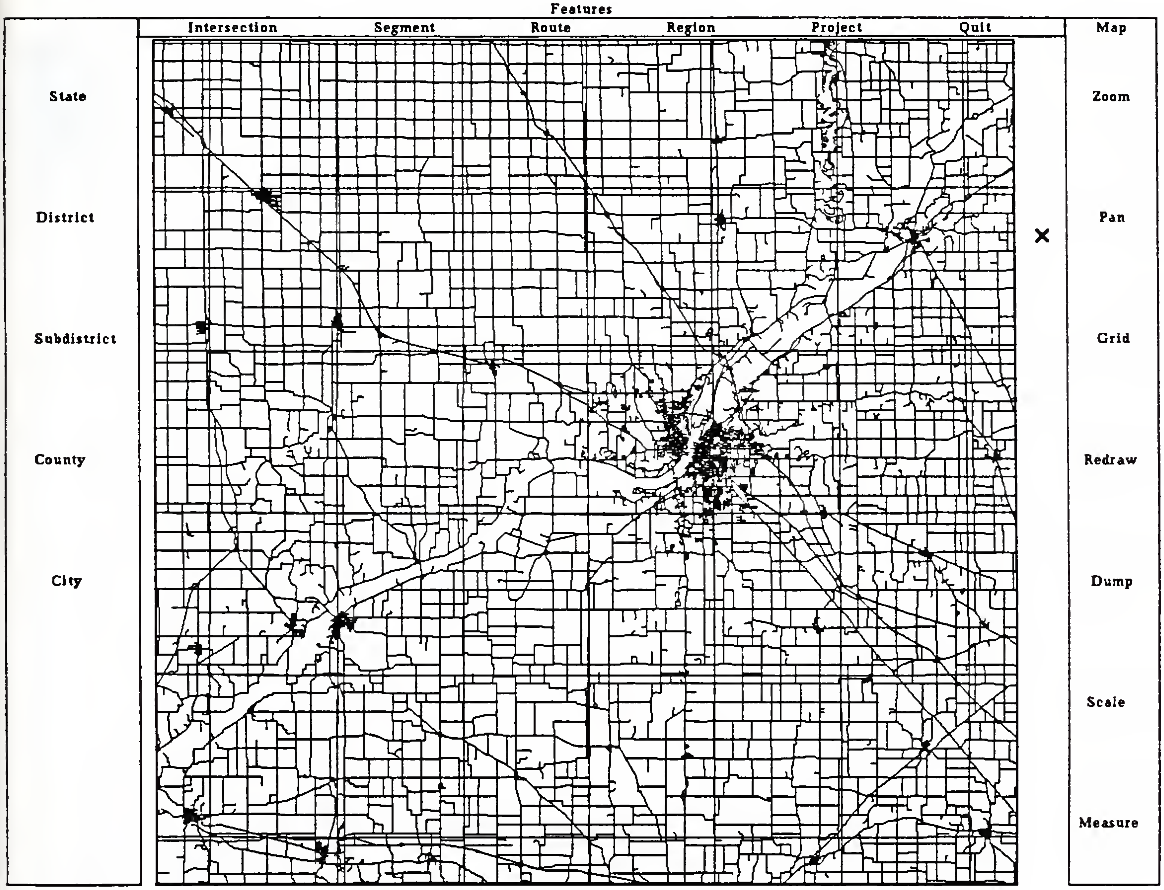

APPENDIX B - Sample SNORODES Session

SNOw ROute Design and Evaluation System



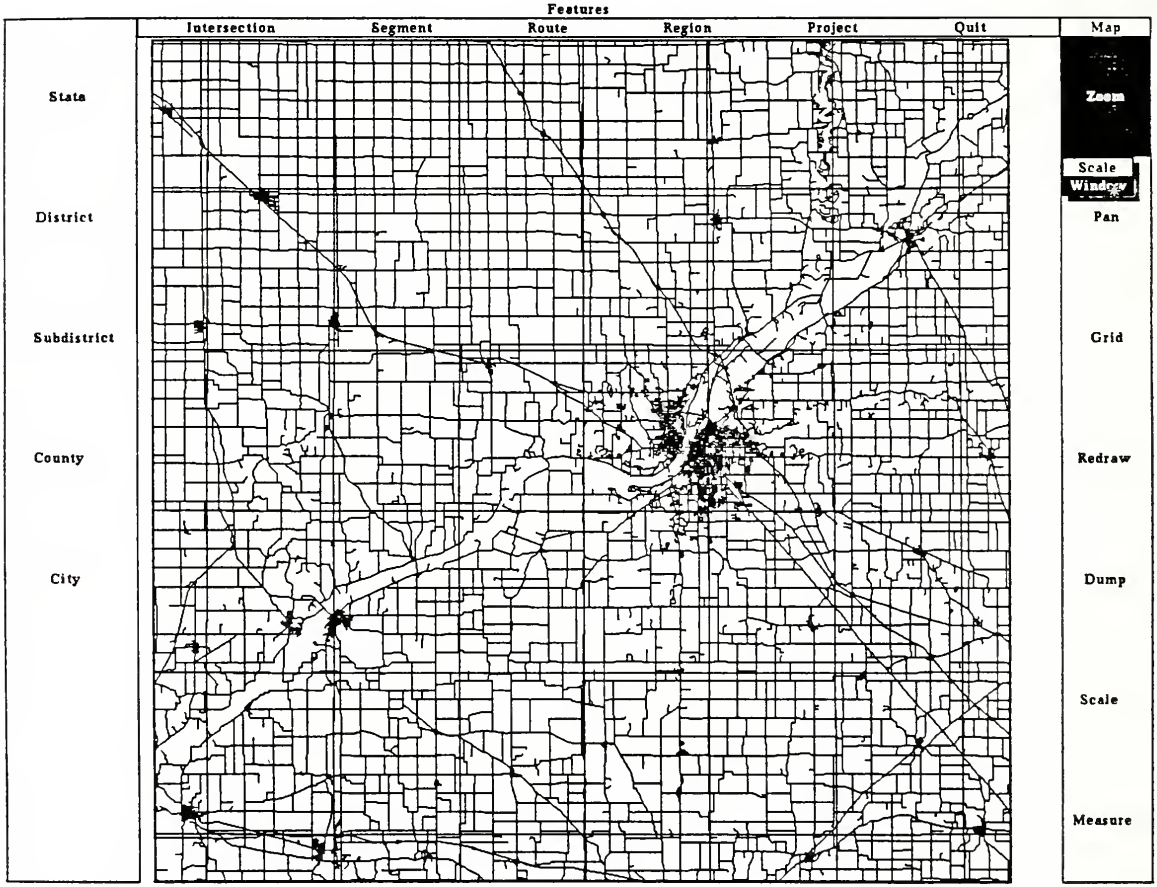
The SNOw ROute Design and Evaluation System (SNORODES) is a highly interactive interface to an extensive roadway information management system. The SNORODES prototype is presently being used to study the design of snow and ice control routes for the Indiana Department of Highways (IDOH). The SNORODES display consists of a large information display screen (center portion of the screen) and three separate menu strips along the top and sides of the display window. The menu strip along the right controls map manipulation. The menu strip along the tip controls feature location. And the strip along the left allows information summaries at various levels. By *pointing* at a particular data cell (shaded square on the Indiana Outline) the user may request the desired map reference...

In this example, the *mouse cursor* **—X—** is placed in the center of the 4 data cells and a button on the mouse is pressed. This results in the display of the corresponding map(s) in the display window as shown below (the region being used for the test case includes the Fowler Subdistrict of the Crawfordsville District Office, IDOH). The map being displayed may be changed in several ways using the menu strip along the right hand side of the screen. Such things as zooming (changing the field of view), panning (changing the map position), and various scaling and measurement features are available as well as options for printing map displays.



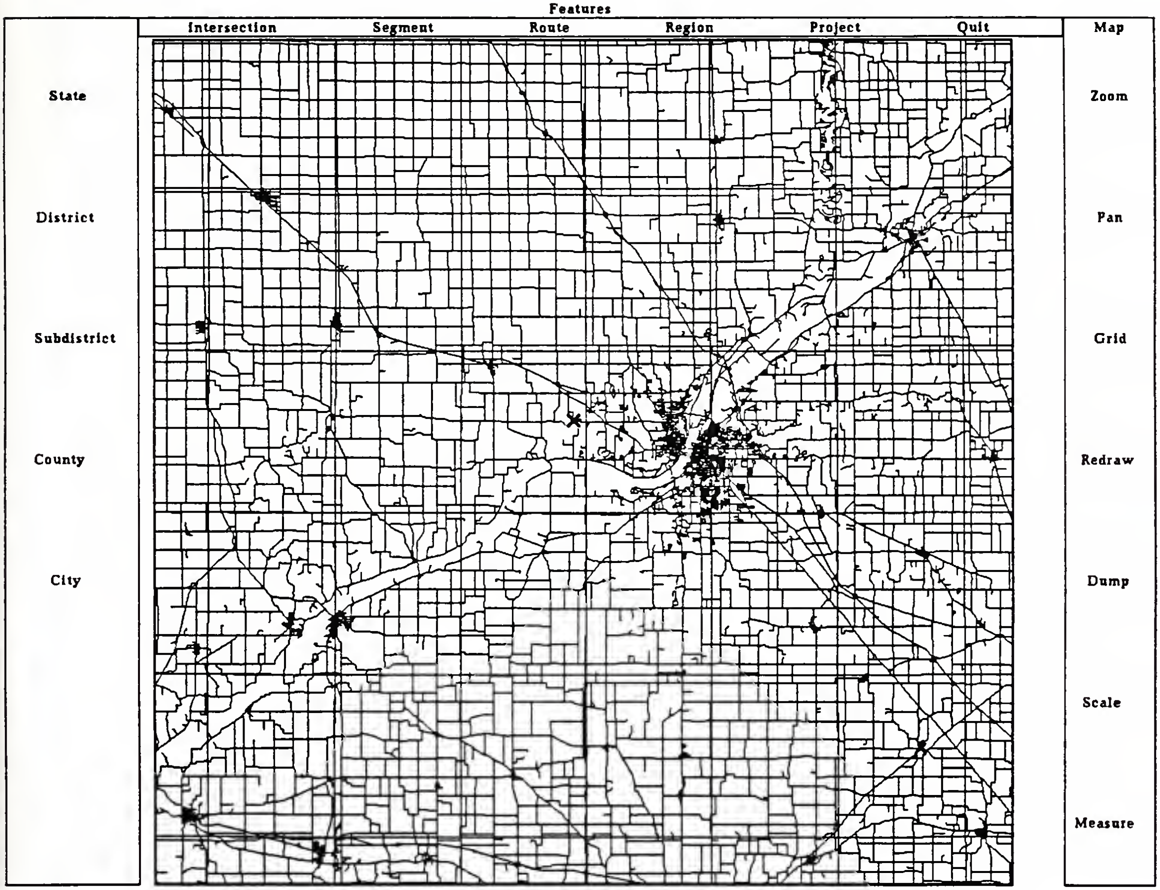
Suppose, for example, we are interested in looking at a smaller region just to the West of West Lafayette along the Wabash River. To select the zoom option from the menu strip, we would position the cursor near the "zoom" menu label using the mouse. When the cursor is correctly positioned, the menu item is shaded as shown in the following display.

By pushing or "clicking" a mouse button with the cursor in this position, a second menu—a zoom menu— emerges and a new cursor—*— appears to emphasize a change in user mode. As with most SNORODES routines, several options exist for conducting the zoom operation. In this case we may select a "scale" option allowing us to change the power-of-magnification on the display window, or a "window" zoom operation. We demonstrate the window zoom option by positioning the cursor in the "Window" option cell and clicking a mouse button.

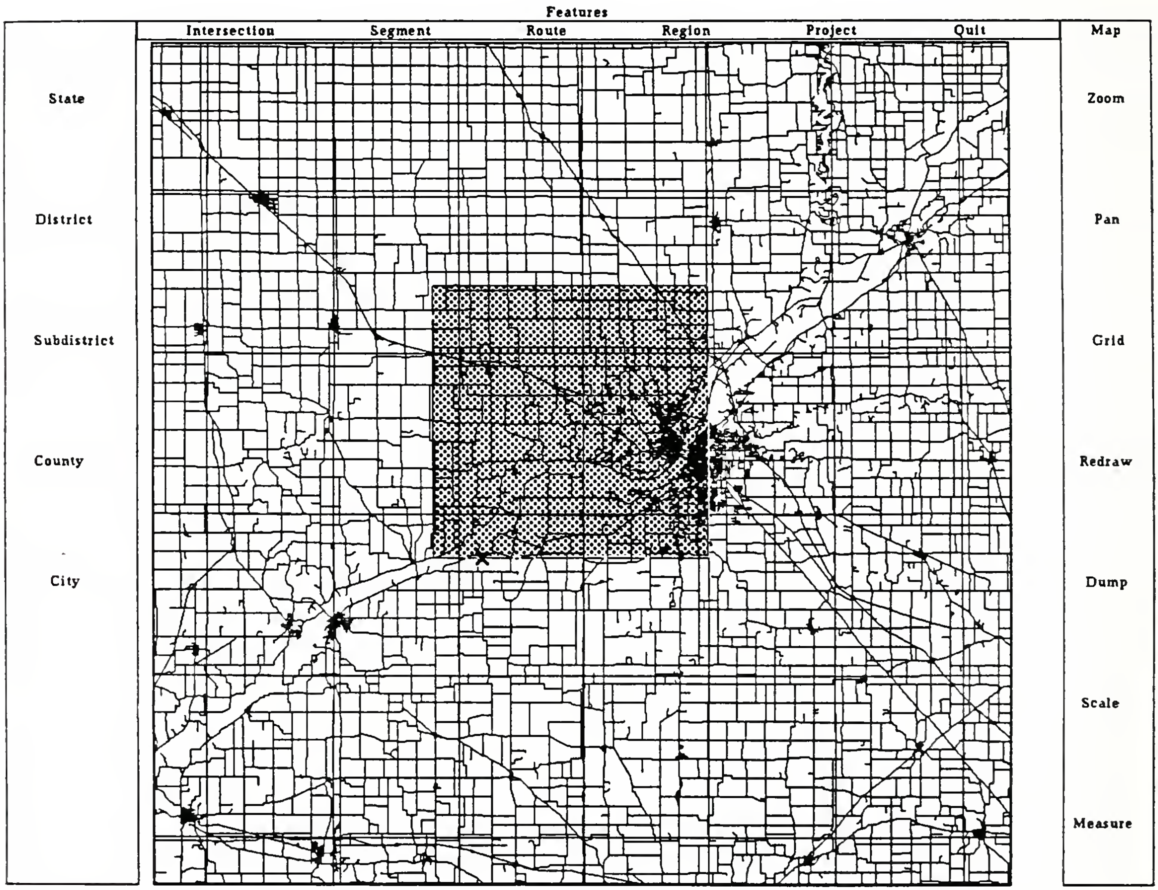


The window zoom procedure assumes that the user is interested in zooming in on a specific feature or region. The user identifies that feature as closely as possible on the current map display and positions the cursor at that location. That point will become the center of the zoomed display when the user clicks a mouse button. In this example, the cursor position is near the center of the display window.

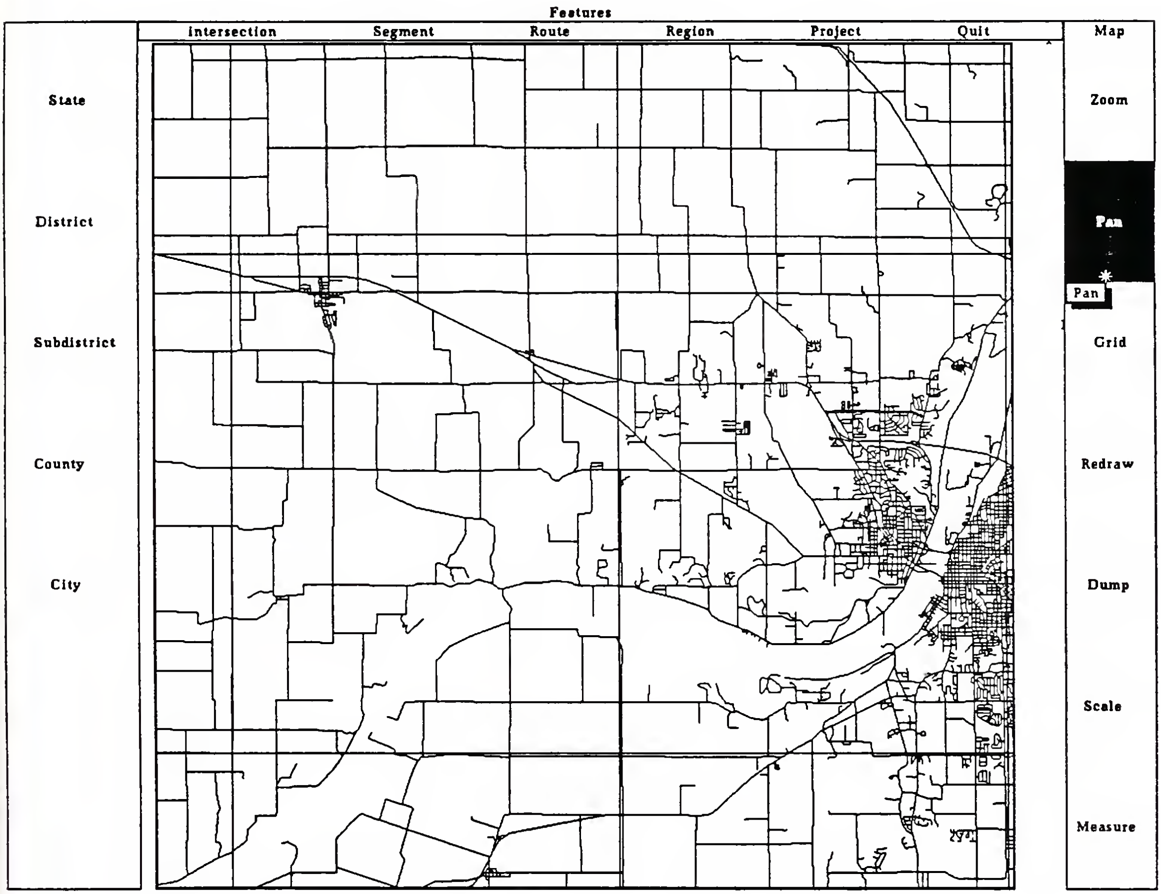
At present, there are no explicit instructions for the user when using this zoom procedure. Future plans call for the inclusion of a small instruction window across the bottom of the display window that will provide access to more extensive "help" routines.



Next, the user must decide how big the resulting zoomed window display will be. As the user moves the cursor away from the center point, an *elastic window* grows with proportions equal to those of the display window. The shaded square near the center of the display window in the figure below represents this sizing window. When the mouse button is pressed a second time, the size of the resulting zoomed window is established; the map area in the sizing window will be enlarged to fill the display window as shown in the following display.

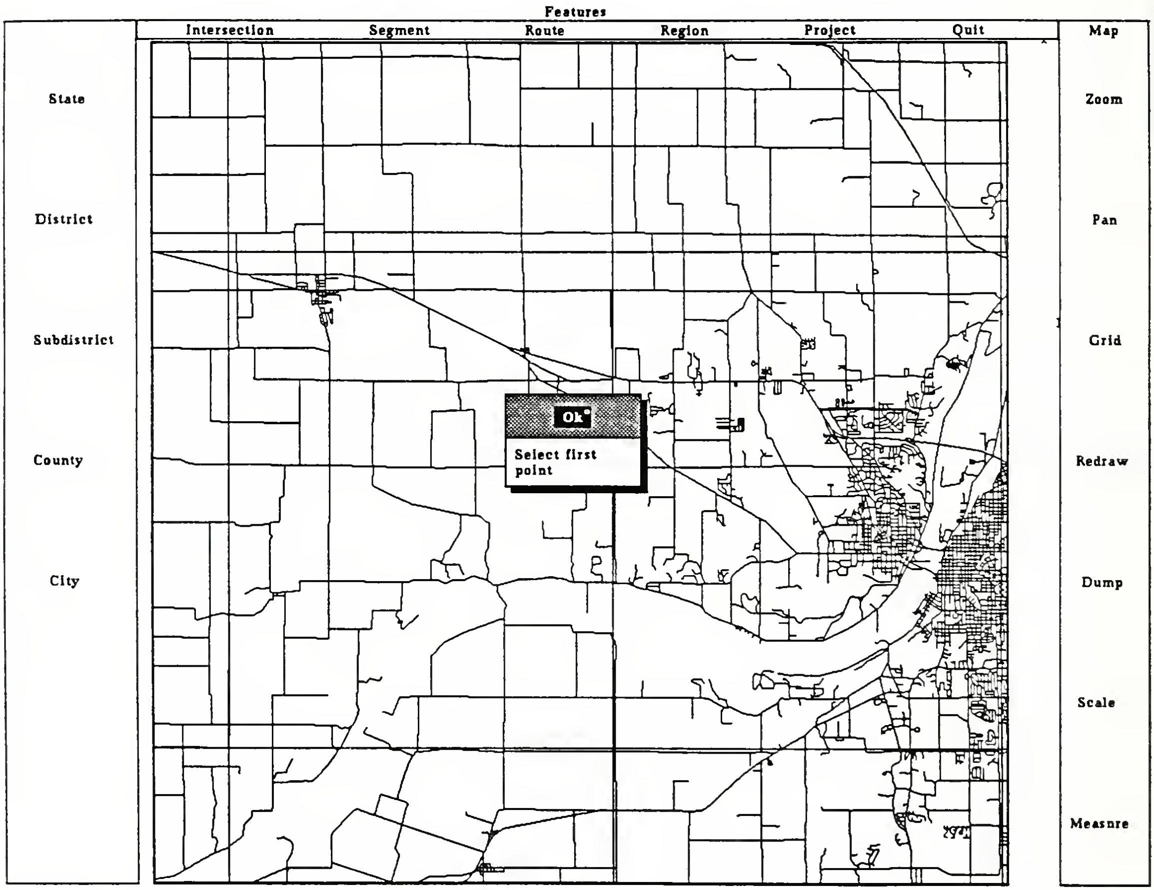


Another map manipulation capability is the "pan" procedure that allows the displayed map to be moved in the display window. The magnification of the map image remains unchanged during this procedure. At present, only one pan option exists which is invoked in a manner similar to the zoom option. First, the user moves the cursor to the general vicinity of the pan menu label and invokes the sub-menu. Once again, the label is shaded to confirm the selection and the cursor is changed for sub-menu selection.

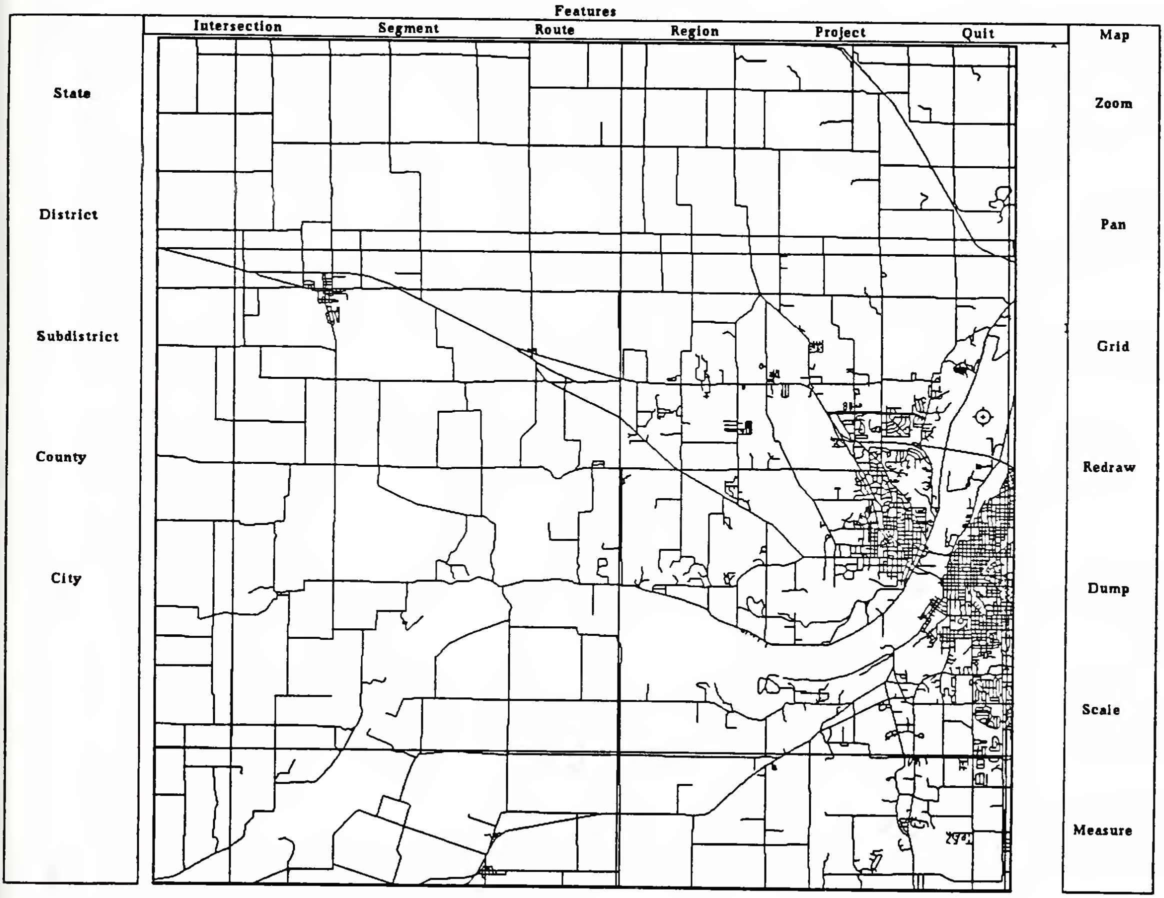


A pan is conducted in four steps. First, the user is asked to select a point anywhere on the display map. This point will subsequently be moved to another location on the display window achieving a shifting of the present map image without changing magnification. After confirming the instruction by clicking the mouse in the "ok" button, the user moves a target cursor to the desired location on the map.

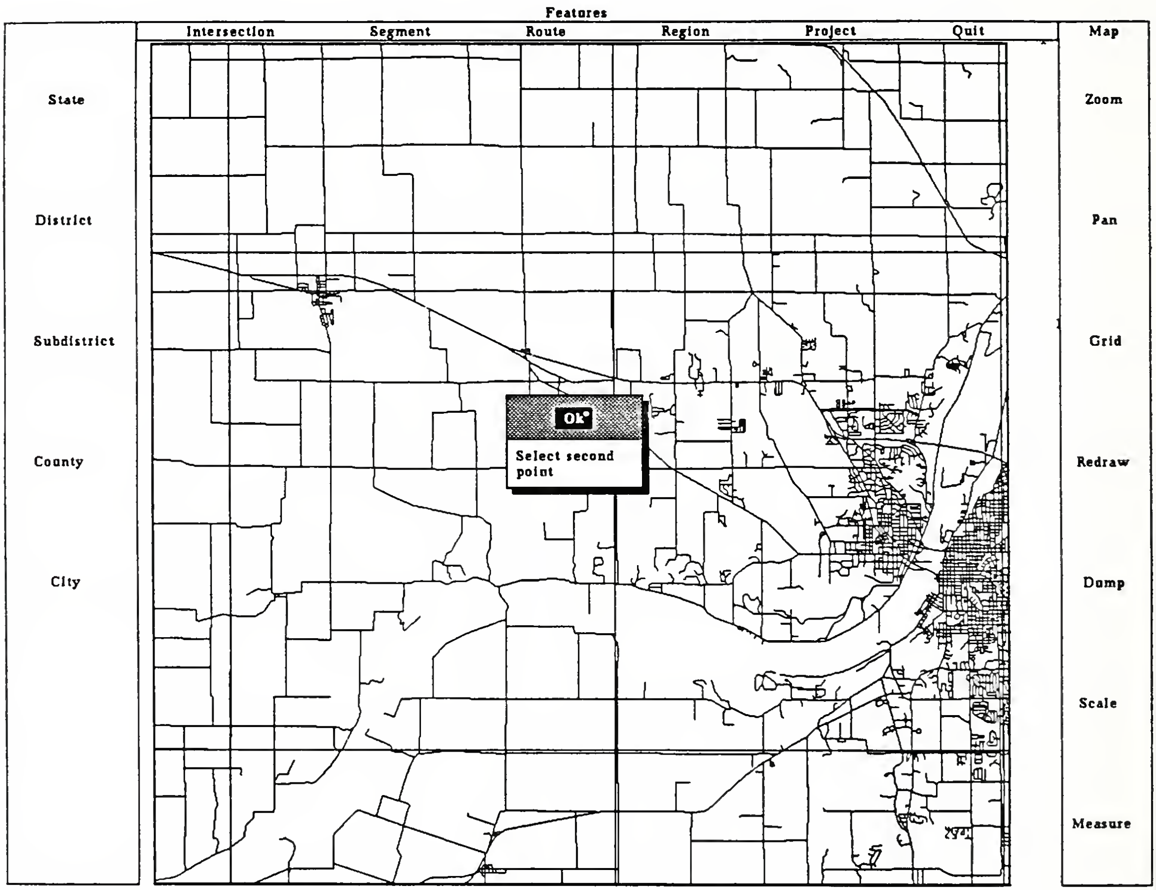
Note that for purposes of this example, a different level of magnification is used to bring out important map detail.



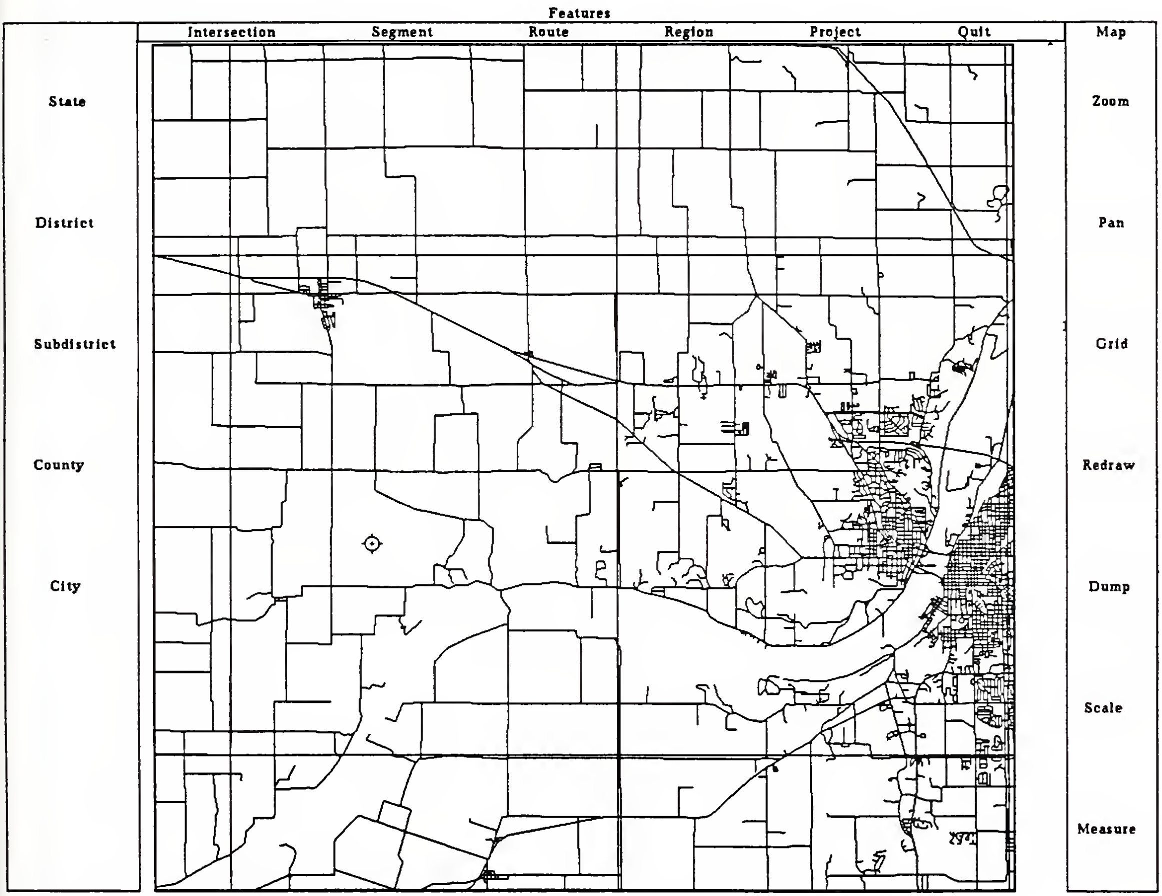
In this example, the user has chosen a point very near the right edge of the display window; a point in the approximate center of the Wabash River. When the user clicks the mouse at this point, a request for a second point is made.



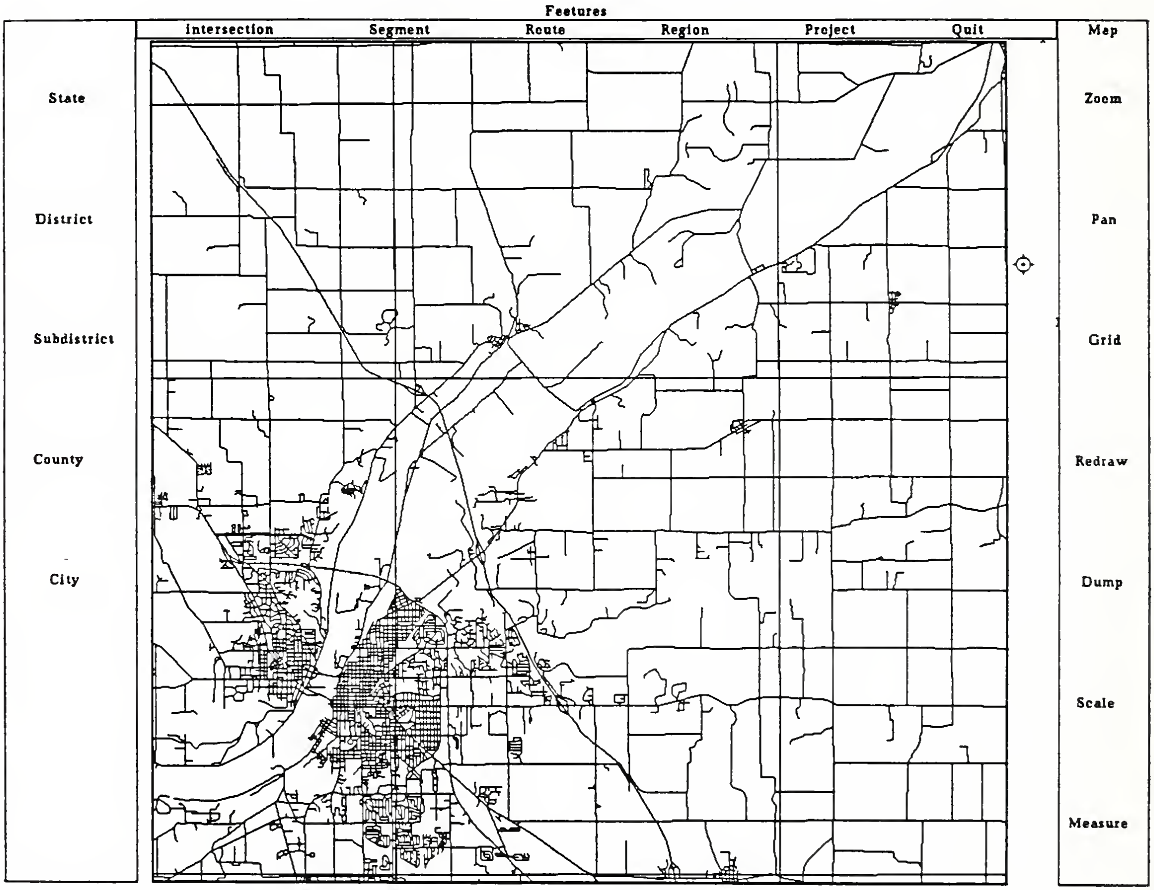
This second point in the display window will become the new position of the first point selected. That is, the first point selected will be *dragged* to the window location of the second point and with it, the map will be moved achieving the pan manipulation. Once again, the user is asked to confirm the instruction.



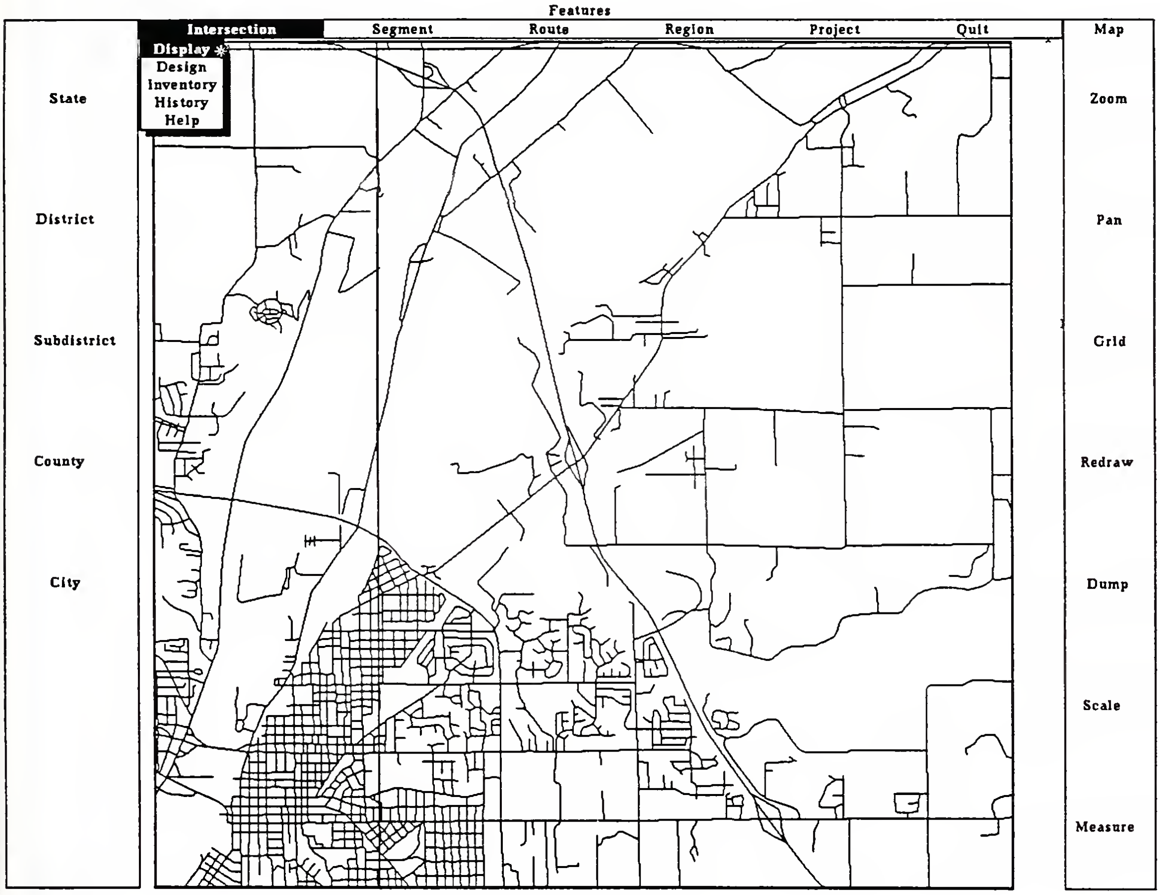
For our example, the second point selected by the user is approximately half way between the center of the display and the left edge, about 40% up from the bottom of the display. When the user clicks the mouse at this point...



...the screen display is redrawn with the map shifted to the left in the window. The first point selected now occupies the location of the second point selected. Using an appropriate combination of the pan and zoom options, the user may display any portion of the highway network that is desired and at any level of detail. Using other map manipulation options, any map display may be scaled, measured (point-to-point) or printed.

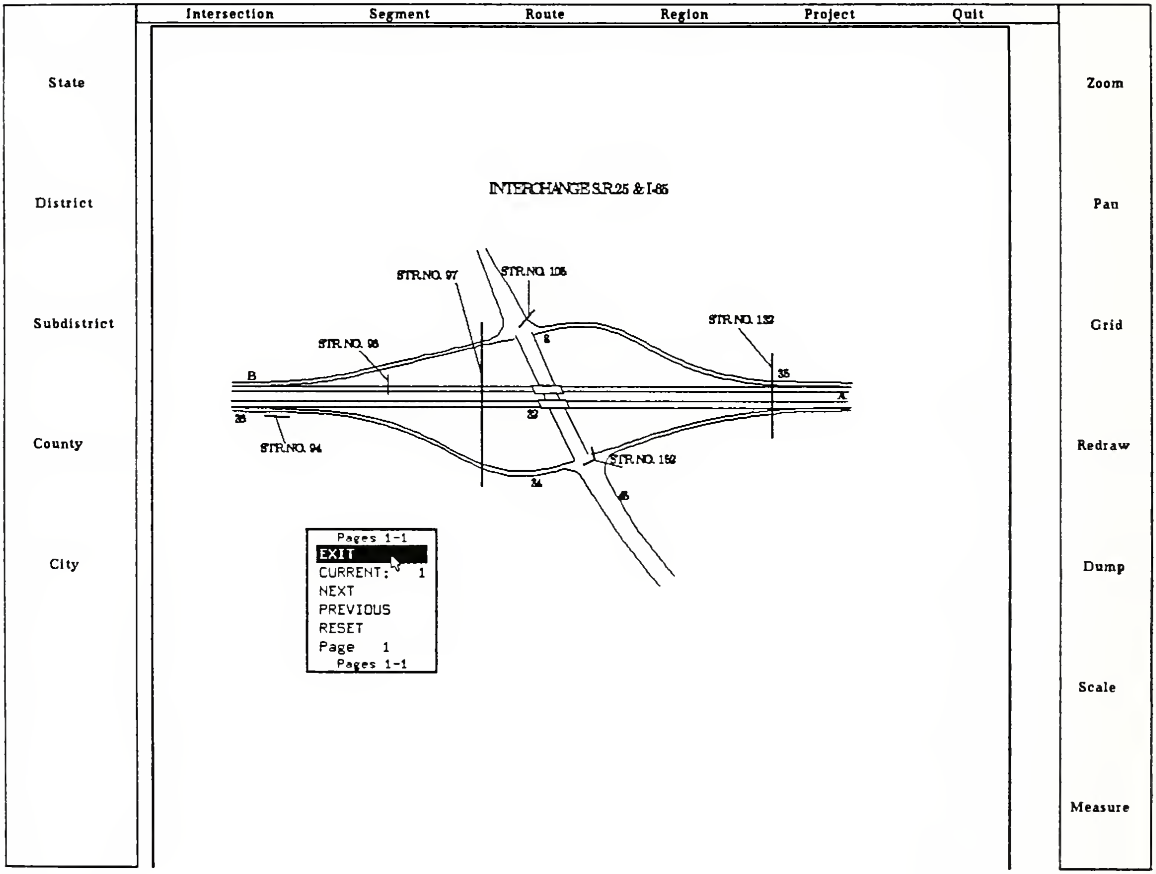


The *feature location* menu located across the top of the display window may be used at any time to locate portions of the network of interest according to type. For example, a user might be interested in locating a particular roadway segment or route, or possibly a specific project. All features may be linked to sophisticated database structures for detailed analysis. As an example, suppose we are interested in information about a particular intersection on the network. We may use the mouse to locate the "Intersection" menu label and select the "Display" option from the sub-menu.

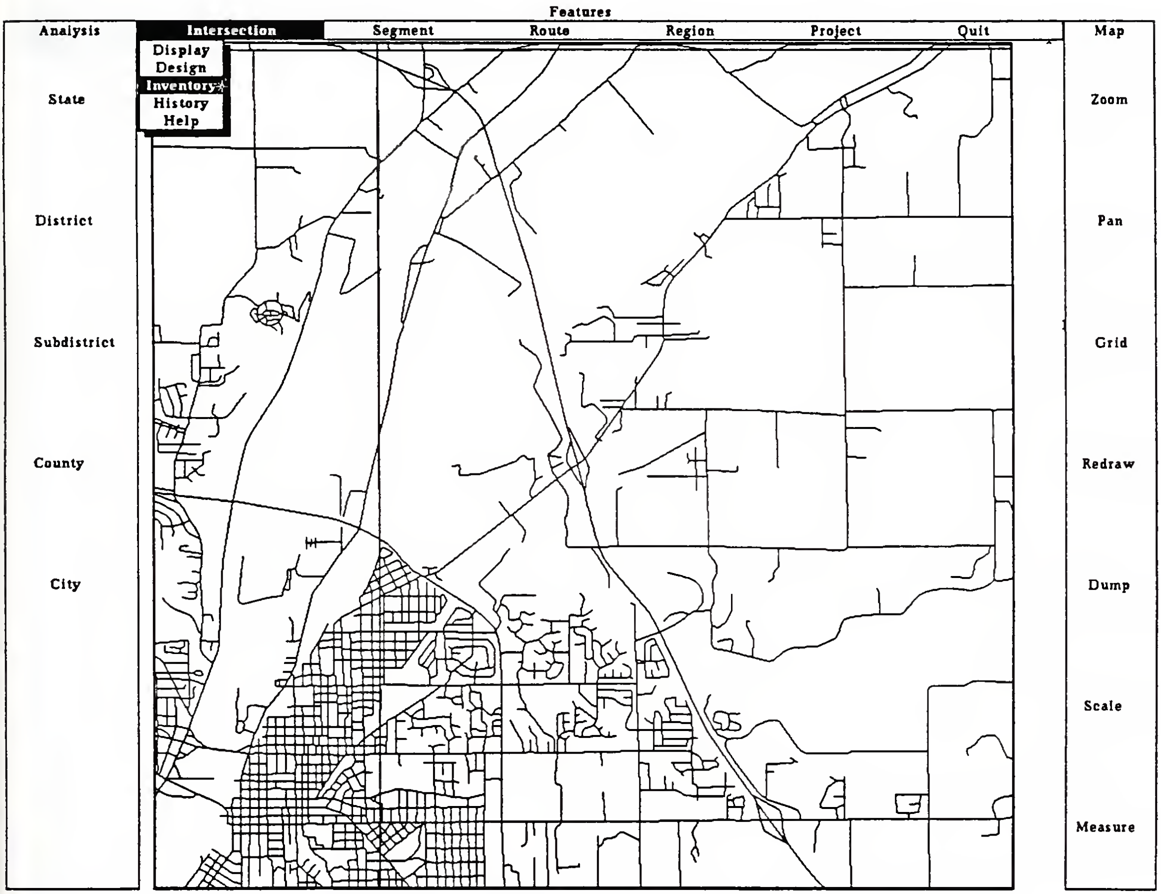


Suppose we are interested in the intersection of I-65 and SR-25, which is displayed near the center of the map. After choosing the display option, we would click the mouse in the vicinity of that intersection resulting in the display of the first of possibly several design drawings of that intersection.

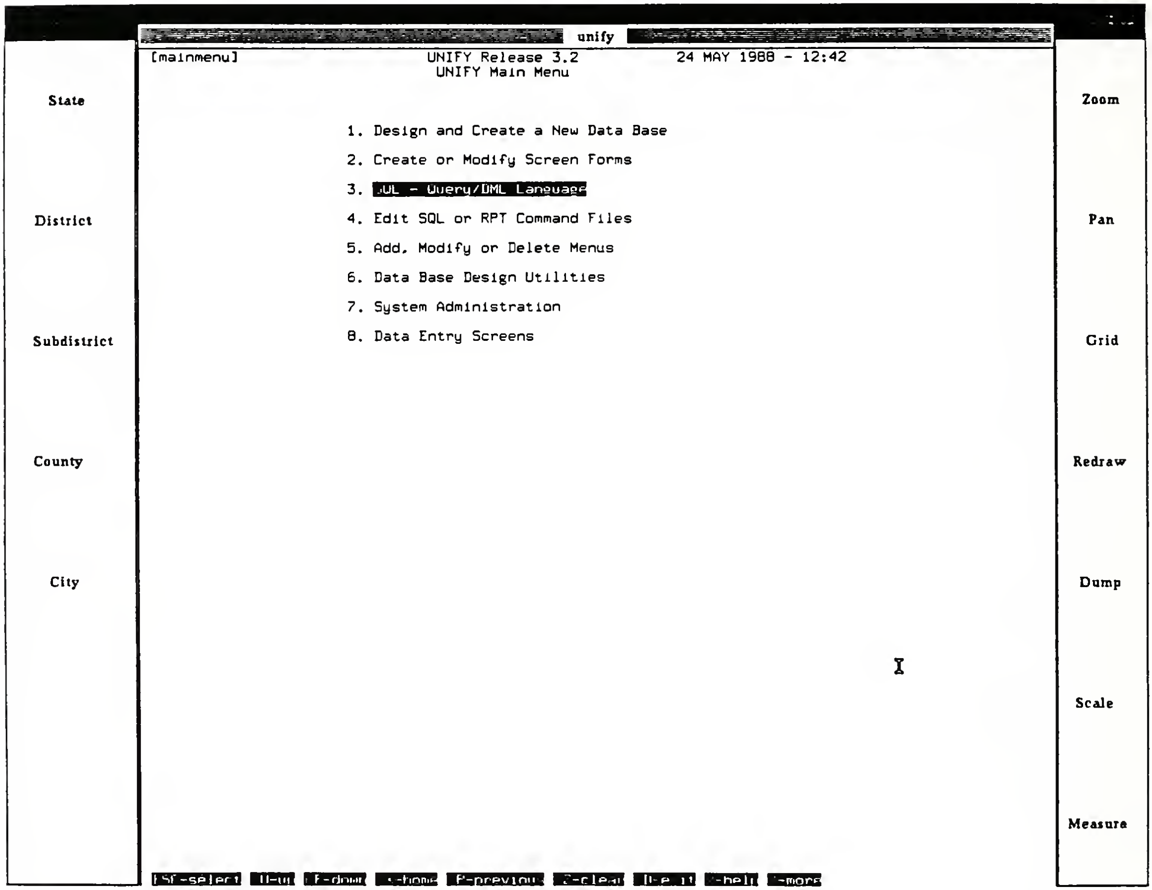
The drawing shown in this example is a very crude representation of an actual design blueprint. But it serves to demonstrate that all important features of the intersection may be represented visually on the screen in much the same fashion as they exist in paper form. Though there is only one such drawing for this example, multiple drawings could be displayed as controlled by a menu that may be "raised" by the click of a mouse button. With program modifications, each drawing could be modified in a design change operation using a modern computer aided design (CAD) program.



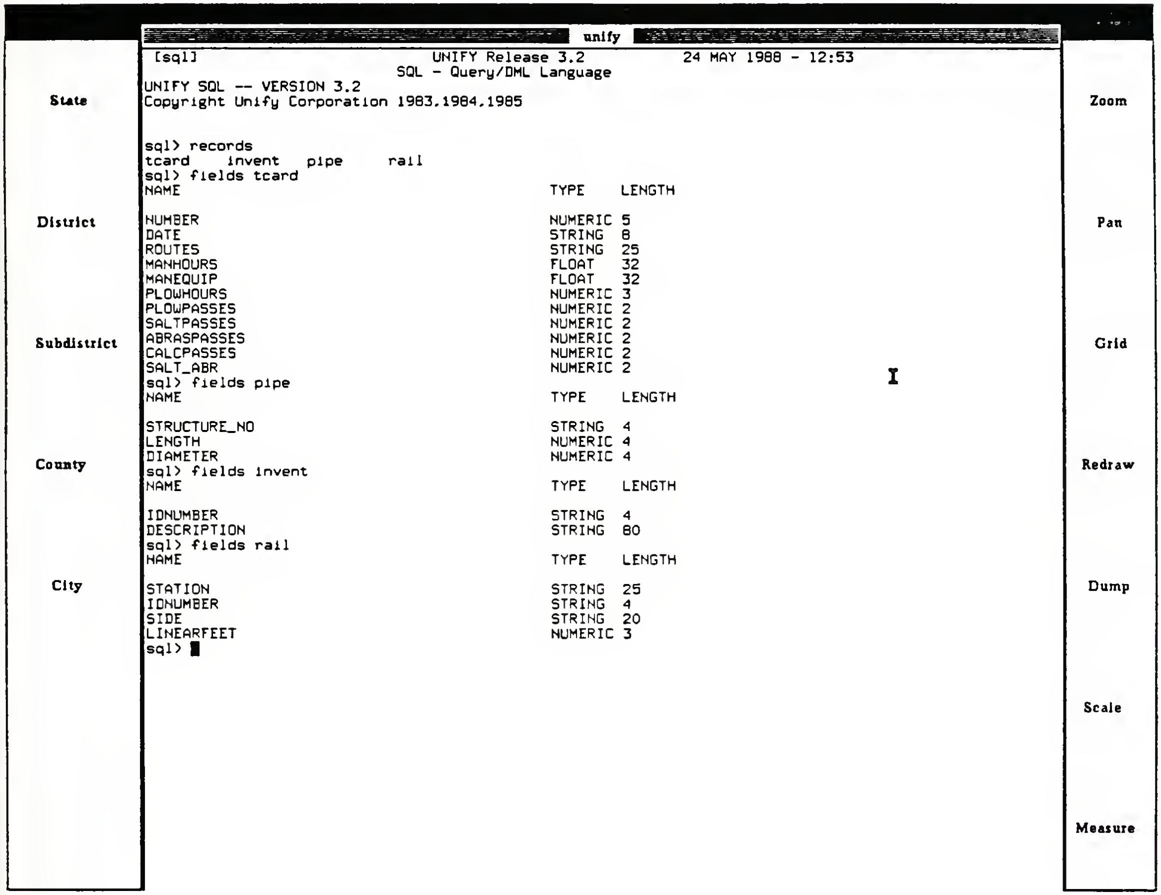
Next, the database management function of the system is demonstrated. Suppose we are interested in conducting an inventory of items at that intersection or in locating specific characteristics or a history of a particular item. By selecting the "Inventory" option from the Intersection sub-menu, the main display window changes to a database menu.



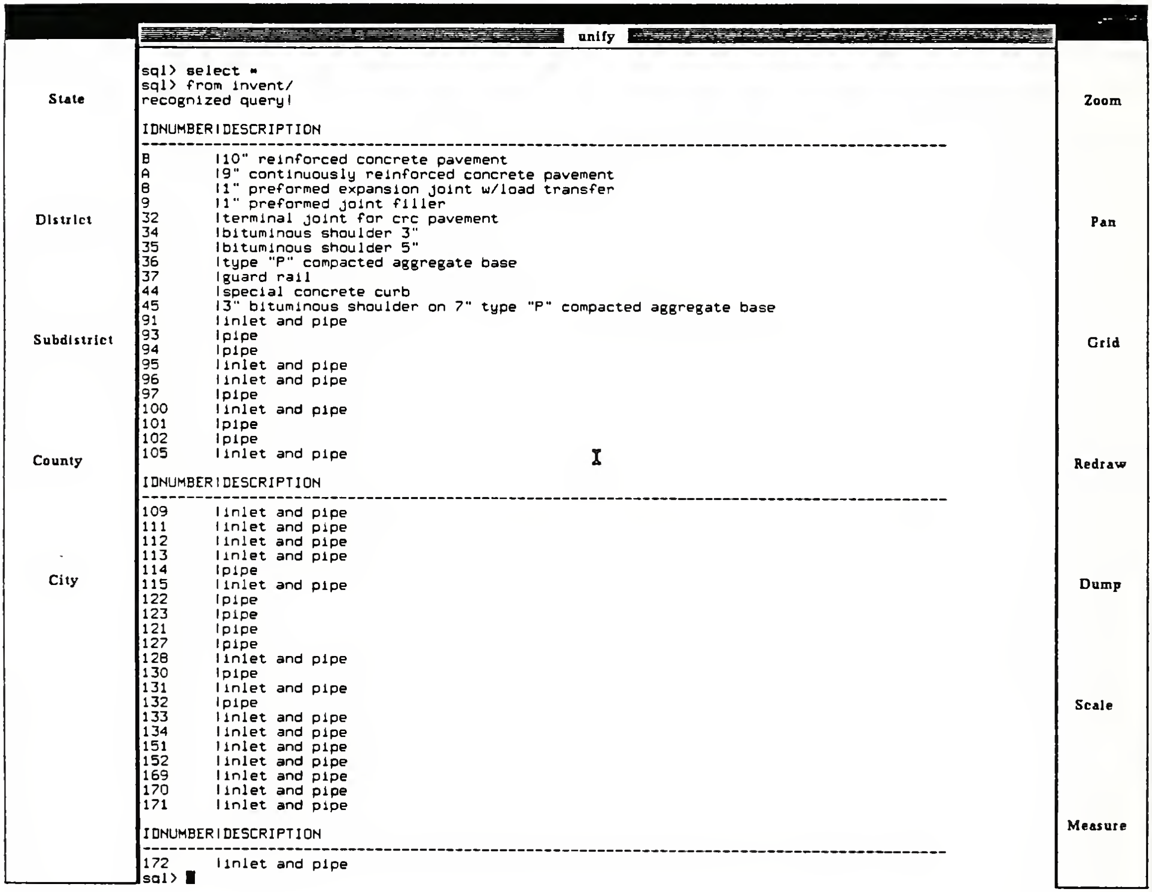
Several options are also available within the database system. We we will invoke a query option—menu item number 3— so that we may investigate the materials inventory for the intersection.



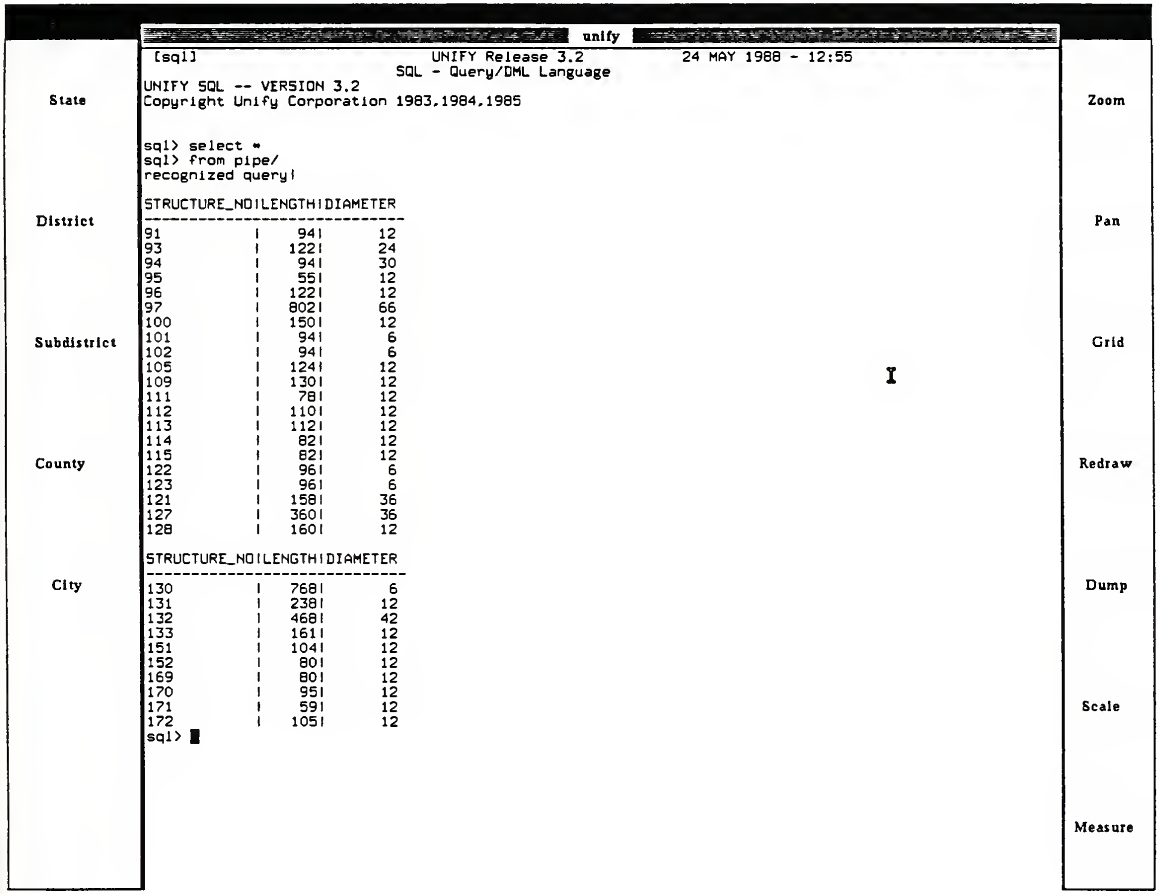
Using the standard query language (SQL) available on all major database management systems, we can first display the records and field specifications making up the schema of this system. In this case, four different database record types have been specified: tcard (time card information), invent (location inventory), pipe, and rail.



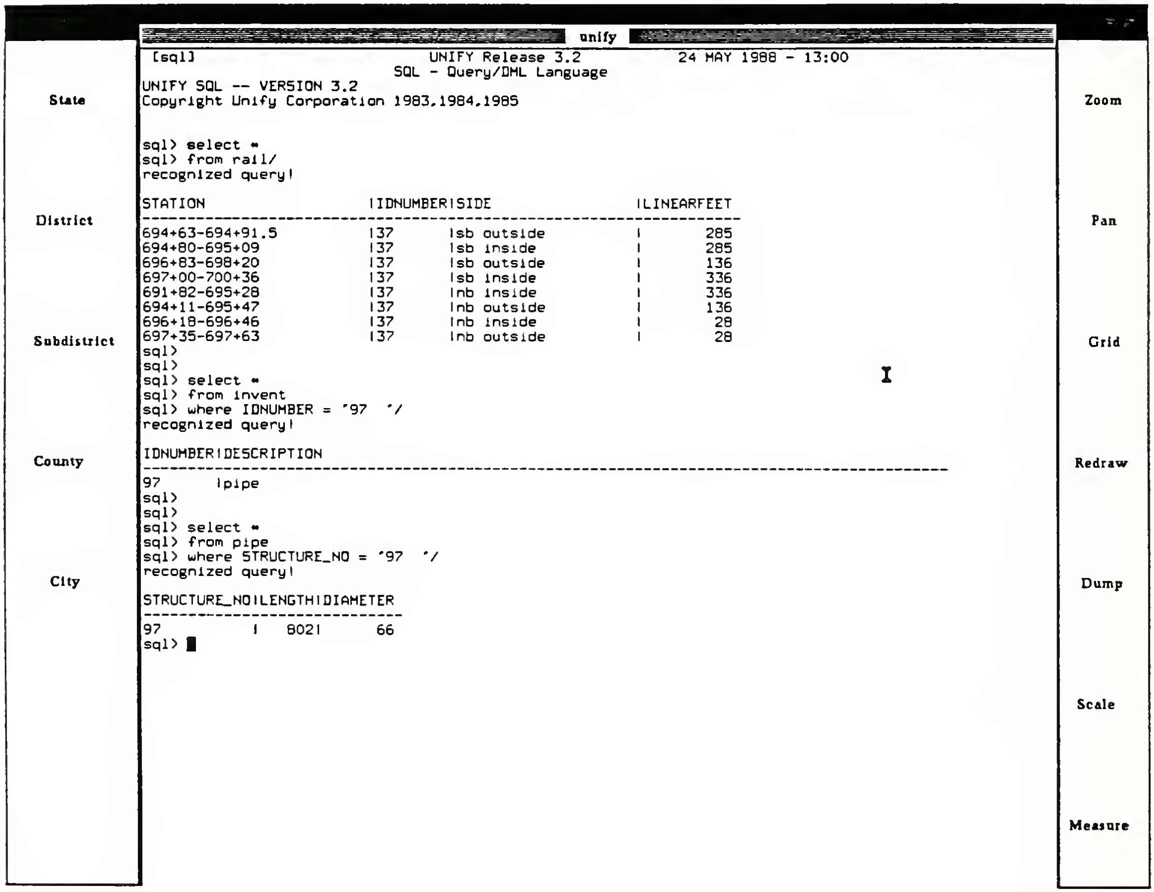
A series of query calls to the database will demonstrate its convenience and flexibility. First, we would like a listing of all major inventory items at that location. The request `select * from invent` says "from the database 'invnet', select all items (*) and display the results of this operation." The result is a listing, by item ID number and description.



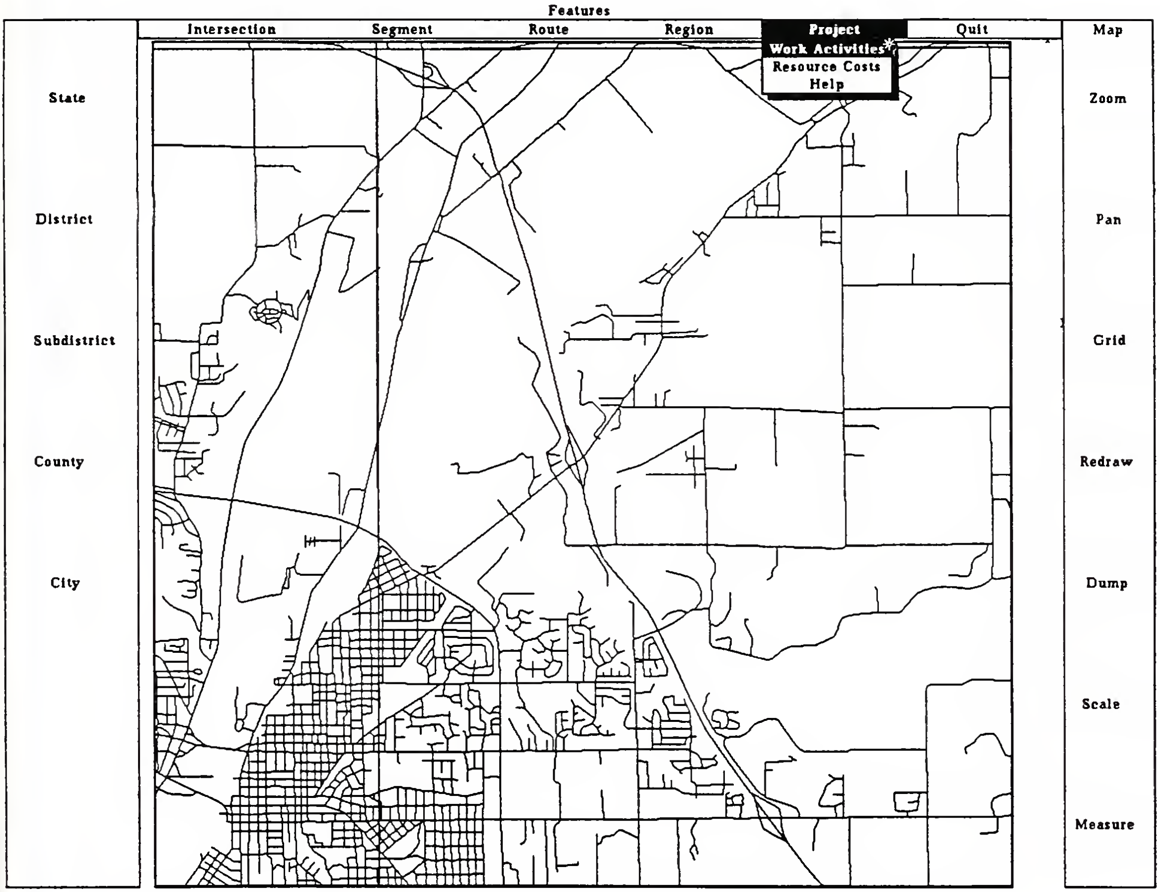
A similar query can be made to get a complete listing of the contents of the pipe record...



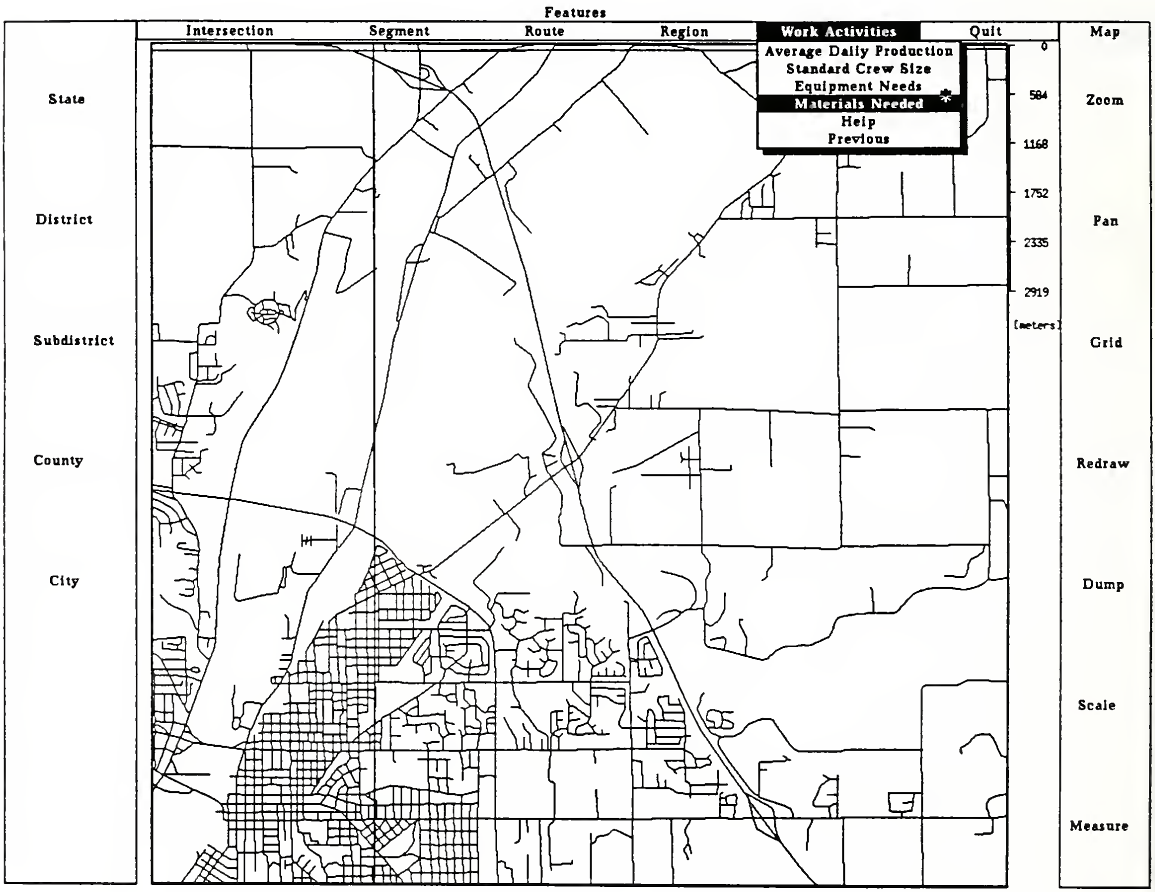
...and from the rail database record. But much more complicated (and presumably useful) database queries can also be made. For example, the query `select * from invent where IDNUMBER = ' 97'` will result in a listing of only that item from the inventory record having IDNUMBER of 97. Combined requests can be made between attributes of different database records as well.



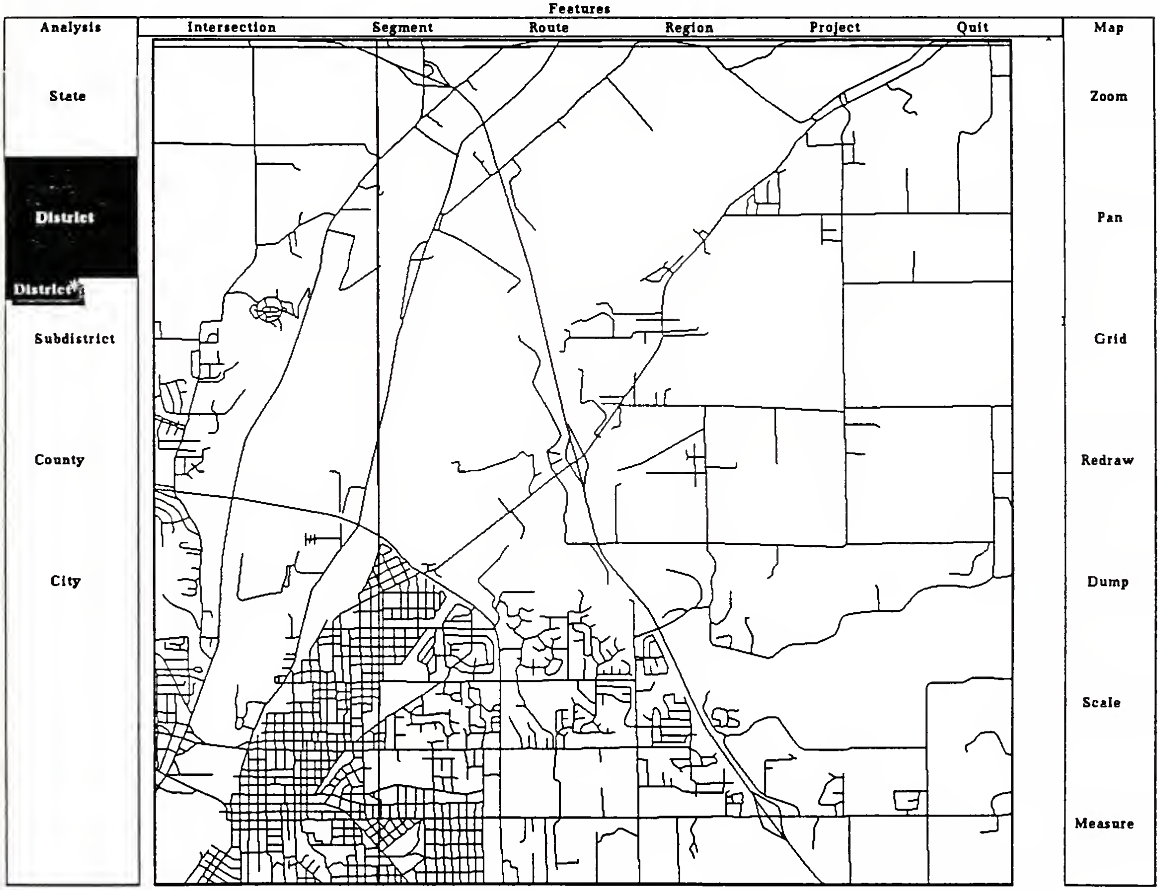
The SNORODES system is modeled after the specifications for the IDOH Maintenance Mangement System as much as possible. For example, the "Projects" item on the features menu has a sub-menu consisting of "Work Activities" and "Resource Costs." The selection of the Work Activities option results in a second sub-menu as shown on the following display.



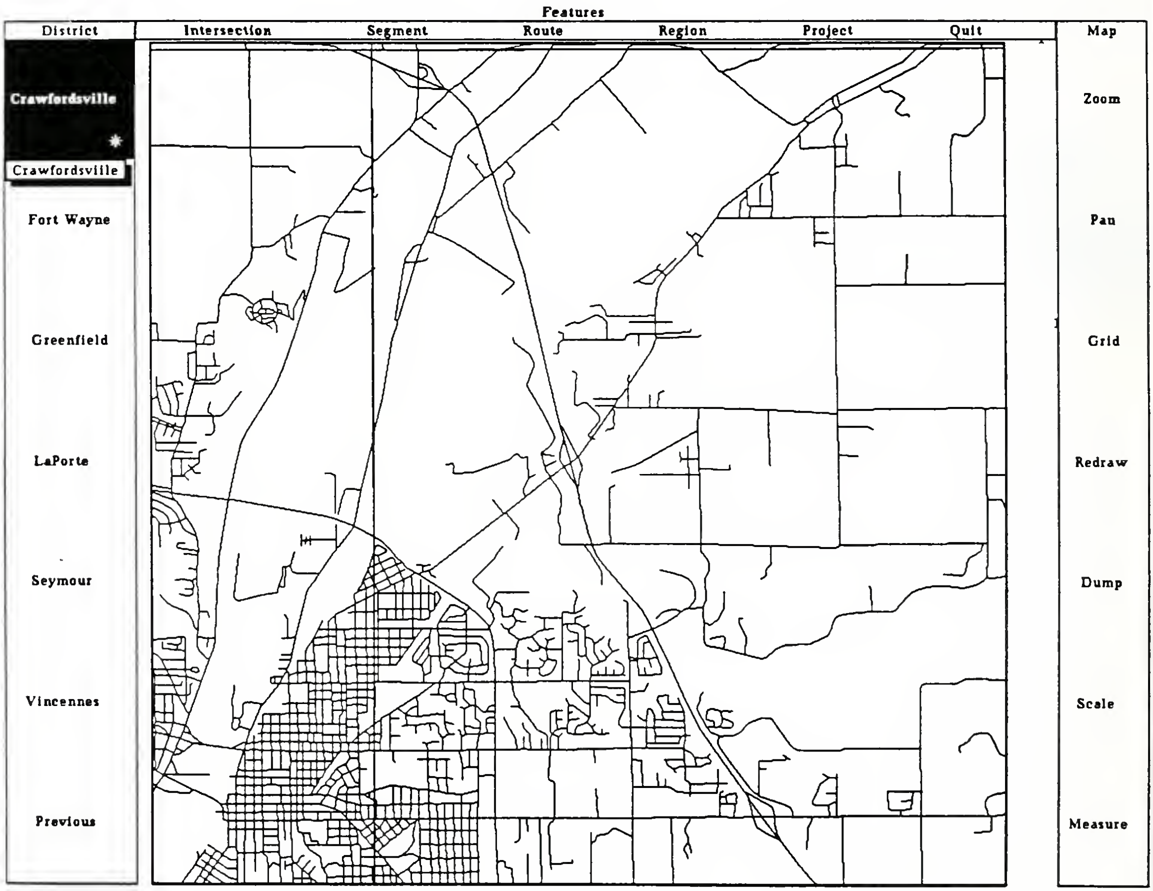
Each of the items in the Work Activities sub-menu— Average Daily Production, Standard Crew Size, Equipment Needs, and Materials Needed—pertain to some aspect of a specific project. This information might be useful in the preparation of weekly, monthly, and final project reports as well as providing current information about all aspects of a given project at any point in time.



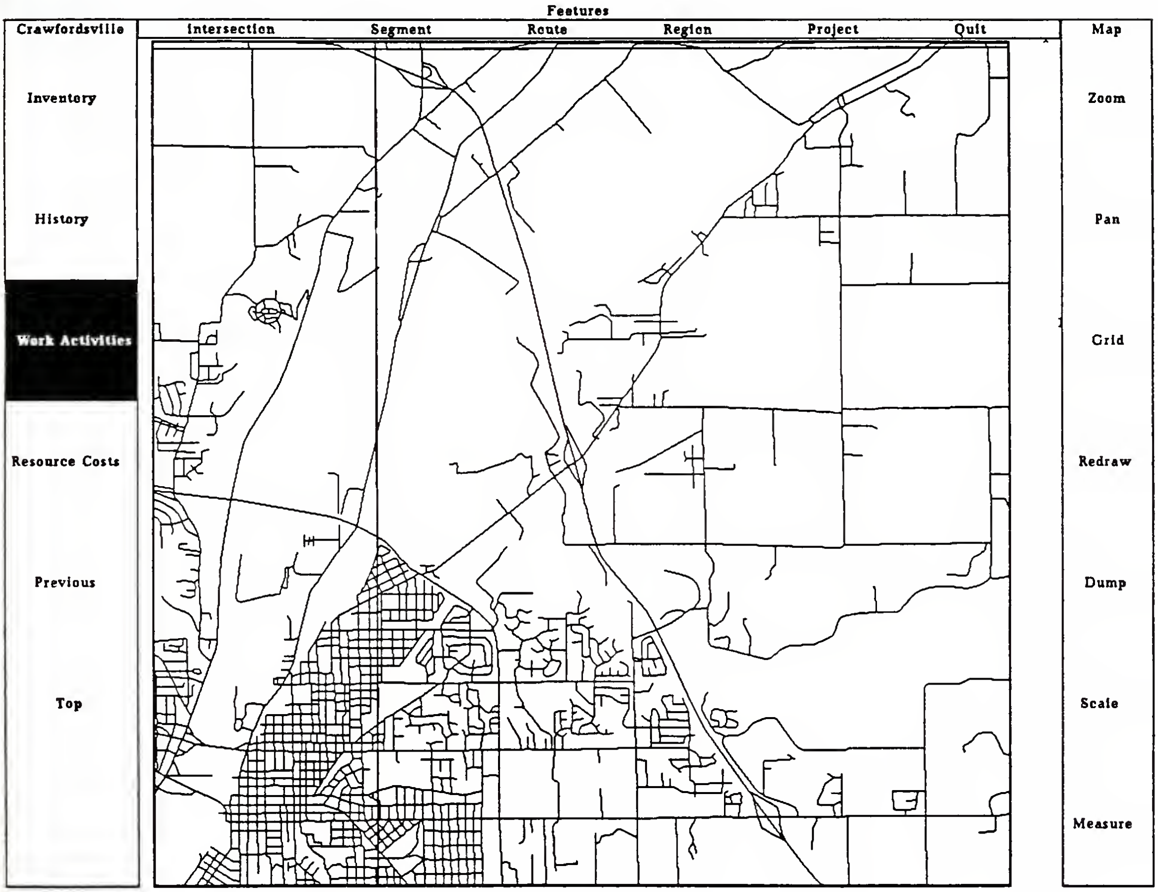
The "Analysis" menu items located along the left side of the display window allow the user to generate and analyze summary information at different levels of operation. One might be interested in State-wide information such as total expenditures for a particular activity within all districts. Alternately, we might be interested in a specific item of information within some smaller regional unit. As an example, suppose we are interested in the total work level on a particular route within the Crawfordsville Sub-district. We would first select the "District" analysis level...



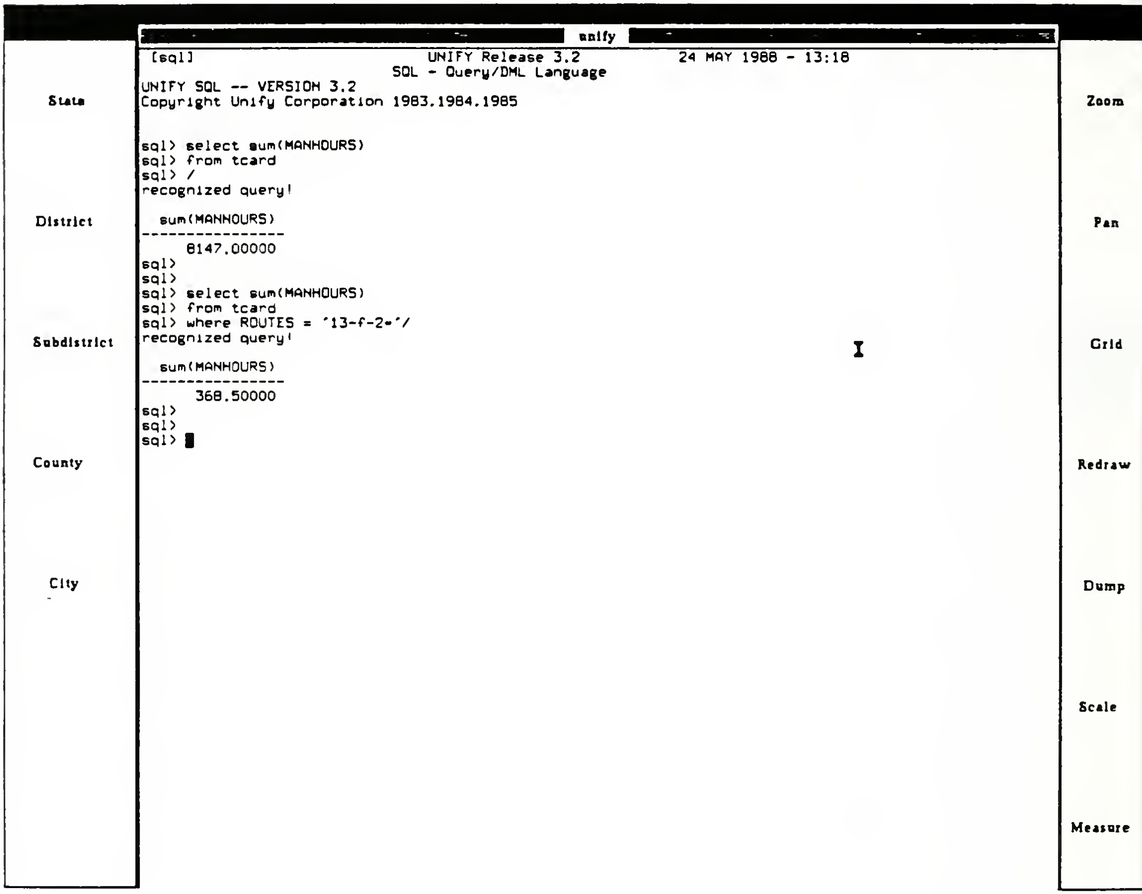
...then select the Crawfordsville District...



...then select the "Work Activities" menu item. This selection will return us to the database query window where we can perform different analyses on the information contained there.



Once again, we may formulate rather complex requests to the database using convenient syntax. `select sum(MANHOURS) from tcard` performs a simple addition of total manhours from the appropriate entry in the tcard database. To be more specific for the route of interest, the query `select sum(MANHOURS) from tcard where ROUTES = '13-f-2*'` reports the total work effort on those routes having identifications starting with the string 13-f-2.



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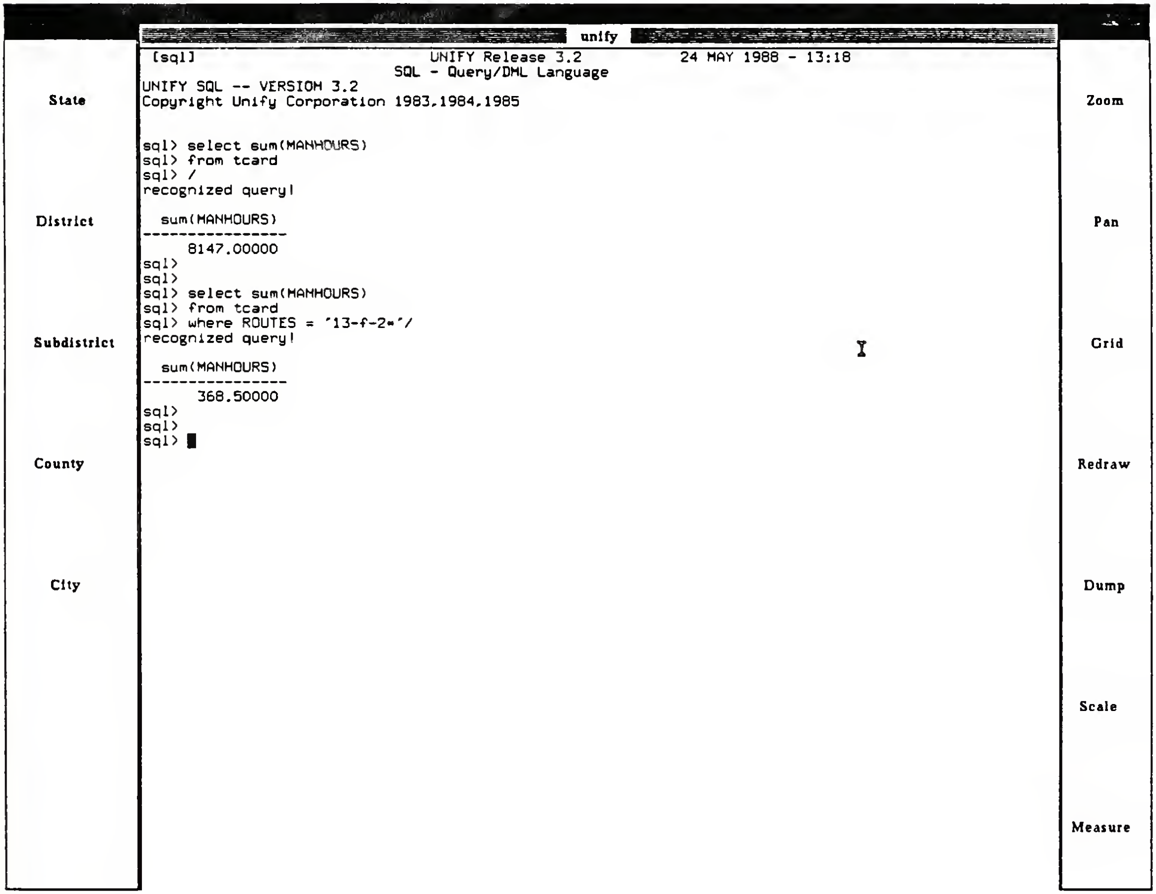

APPENDIX C - Glossary

Glossary

Attribute codes. A pair of figures to describe the class of a road

Client An application program

Lagrangian relaxation. A technique of optimization

Protocal. A mechanism to connect application program to the workstation

Socket. A file which can send data into process on a UNIX system

USGS. United States Geological Survey

XML. A mechanism to generate the input for XMP

XMP. An optimization software

lwxpr. A command to print the screen dump file from a laser printer

xwd. A command in X window to dump the contents of a certain screen

COVER DESIGN BY ALDO GIORGINI